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Examining Different Approaches to Mapping Internet Infrastructure

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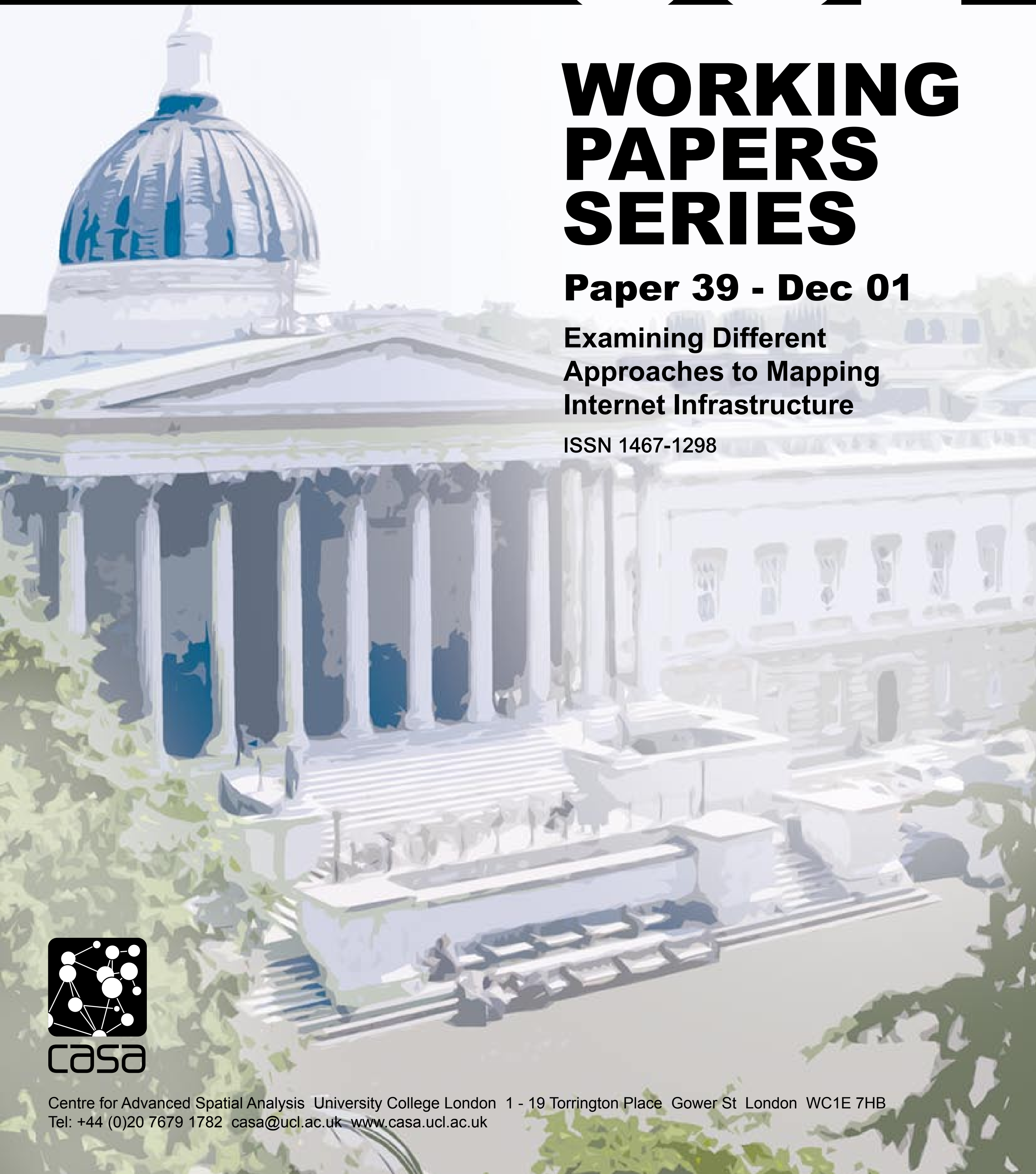

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EXAMINING DIFFERENT APPROACHES TO MAPPING INTERNET INFRASTRUCTURE
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Examining different approaches to mapping Internet infrastructure

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Introduction

Over the last decade or so there has been a phenomenal growth in the use and diversity of information and communications technologies (ICTs), with the rise of Internet being of particular note. Current estimates, as of autumn 2001, are that 513 million people from around the world use the Internet for all manner of personal and business communications (Nua 2001). Concomitant to this growth, there has been a multi-billion dollar investment in vast assemblages of powerful computer servers and the infrastructure necessary to support current and projected demand in information processing and exchange, including long haul fibre-optic backbones networks to link countries and metropolitan cores, high-speed routers and switches, and 'last-mile' DSL and cable connections (see OECD 2001, TeleGeography 2001 for current statistics). This strategic investment is designed to garner market share in the rapidly expanding information economy (worth a reported $775.6 billion in the US alone in 1999; US Census, Service Annual Survey 1999 [1]). Understanding the development and growth of ICTs, the myriad of their social, economic, and political consequences, as well as the practical tasks of planning infrastructure deployment, however, is no easy task. In this chapter, we argue that one useful strategy for analyzing and comprehending the Internet is the application of concepts and techniques from cartography and geographic visualization.

Maps and visualizations have long been used as a way of making the world more comprehensible. Mapping provides a means by which to classify, represent and communicate information about areas that are too large and too complex to be seen directly. Well designed maps are relatively easy-to-interpret, and constitute concentrated databases of information about the location, shape and size of key features of a landscape and the connections between them. Moreover, the process of spatialisation, where a spatial, map-like structure is applied to data where no inherent or obvious one exists, can provide an interpretable structure to large databases of abstract information (Couclelis 1998). In essence, maps and spatialisations exploit the mind's ability to more readily see complex relationships in images, providing a clear understanding of a phenomena, reducing search time, and revealing relationships that may otherwise not been noticed. We illustrate the power of a mapping strategy by focusing on its utility in comprehending Internet infrastructure, although as we detail elsewhere, mapping and spatialisation can be used to develop an understanding of a wide range of Internet uses and content (Dodge and Kitchin 2000a, 2001).

Internet infrastructure, and its use, is often taken for granted because, unlike roads or railways, it is largely invisible: buried underground, snaking across ocean floors, hidden inside wall conduits, or floating unseen in orbit above us. Indeed, given its invisibility it is easy to assume that it is as ethereal and virtual as the information and communication that it supports. Consequently, there are a number of elements to Internet infrastructure that we presently have little systematic knowledge about, such as the form and function of backbone networks and their subsidiaries, network routing and traffic conditions, user demographics, marketing penetration and ownership, the physical location of computer servers (hosts) and Internet addresses, connectivity, and bandwidth. The mapping of these elements we believe

[1] http://www.census.gov/econ/www/servmenu.html

serves a number of useful functions providing important insights into who owns and controls infrastructure, who has access to the Internet, how the system can be surveyed, and how and from where the Internet is being used. This is vital information for the planning of new provision and the setting of policy and regulatory guidelines.

At a basic level, the maps provide a spatialised inventory and census of *where* Internet nodes and routes of connection are located, and in specific cases the traffic that flows through networks and their user profiles. Maps of network infrastructure can show clearly how computers are physically wired together to create complex networks that operate over several spatial scales, building into global scale systems. Depending on scale these maps can be used by engineers to install and maintain the physical hardware of the networks, by system operators to manage networks more effectively, and by marketing and business development departments to demonstrate the size and penetration of networked services.

In addition, the maps have academic utility by showing significant trends and spatial patterns in the growth of network architecture, service provision, user profiles and traffic flow across spatial scales, so for example, allowing comparison of neighborhoods, cities and countries. As such they reveal the growth of the Network Society and information economy, but also its uneven and unequal geographic nature by revealing the distribution of infrastructure and those areas that have poor access to the Internet or are presently excluded altogether (Castells 2000, 2001). Moreover, they allow an analysis of the changes occurring in these patterns. As recent research highlights, although the Internet has expanded, diversified and diffused greatly, basic infrastructure access and equity issues are still significant; the so called 'digital divide' issue, which is played out in different ways at different spatial scales, and is fractured along lines of wealth, class, race, gender and so on (Norris 2001, NTIA 2000, Warf 2001).

Perhaps not unsurprisingly given its varied nature, maps of Internet infrastructure come in a variety of forms both in terms of what is mapped (e.g. network structure or traffic flows) and how it is mapped. The cartographic designs employed are various. Many examples use conventional approaches of shaded or symbol maps on a familiar geographic framework (these are often produced using standard GIS packages). However, other significant examples stretch the notion of a 'map' using more diagrammatic approaches, for example showing the topology of network connections laid out in a non-geographic, abstract coordinate space. Some of the maps are interactive interfaces using the medium of the map to allow users to access and query the data in novel ways. Some of the most potentially powerful and interesting 'new breed' of infrastructure maps are dynamic in nature, constructed with live data gathered from the Internet every time the map is requested by a user.

In the remainder of the chapter we provide a review of some different projects that have sought to map Internet infrastructure, dividing our discussion into four sections, themed by map purpose: (i) maps for operational Internet management; (ii) maps for Internet marketing; (iii) maps for Internet policy and planning; (iv) maps for academic Internet analysis. Our selection of projects is limited by space, so we have chosen projects that are we feel have particular salience in relation to Internet infrastructure policy and planning, either for the public sector or commercial companies, and importantly are publicly available for wider analysis[2]. The maps are produced by many different people, ranging from interested individuals, to academic research

[2] (for a more comprehensive review see Dodge and Kitchin 2000a, 2001).

groups, consultants and commercial analysts, through to government regulators and network operators and marketing departments at ISPs.

Maps For Operational Internet Management

Managing large-scale and geographically distributed network infrastructure is a challenging and demanding task. Network managers need to insure the fast and uninterrupted flow of gigabytes of data traffic from multiple origin points to many destinations. It requires skill and attention to identify, correctly diagnose and rectify faults in hardware and the complex software systems that control data traffic routing. This is made more challenging by the fact that (1) many ISPs have service agreements with customers that specify a minimum network performance and reliability at the 99.9% mark (or higher), which amounts to acceptable outages equivalent to just 4.4 hours per year; (2) there are significant issues of cooperation between ISPs due to the decentralized and distributed nature of the global Internet. In relation to the latter point, it is often forgotten that the Internet is not a homogeneous single network, but rather a network composed of networks, each of which is owned and operated by separate (often competing) companies and organizations. This means that there is no central command or overall management of the Internet. Consequently, it is often the case that operational network problems, due to hardware failure or misconfiguration of software within one ISP, can impact widely elsewhere in the Internet; a major event at a strategic location on the Internet can have widespread impacts across many networks and affect tens of thousands of users who may be many miles from the event its self[3]. These network problems can be caused by natural events such as hurricanes or earthquakes or man-made, like malicious distributed denial-of-service attacks and network viruses, as well as the accidental 'back-hoe' incidents that cut

[3] Research is showing that the Internet is surprisingly vulnerable to disruption despite its decentralized nature. See for example "The Achilles' heel of the Internet", *Nature*, 27th July 2000 . <http://www.nature.com/nature/fow/000727.html>

major backbone fibre-optic cables (Barrett 1999, Delio 2001). There are also the problems of handling unexpected surges in traffic in response to high profile news events (Ewalt 2001, Manjoo 2000).

In tackling these operational challenges, maps of network architecture and performance can be vital tools for managers and engineers. Maps can summarise and present complex, rapidly changing data on the operational state of a network in a single visual image, providing an easy-to-interpret overview of the system and thereby aiding problem diagnosis and solving. For example, in NOCs (network operations centers) of large ISPs just a handful of skilled operations are responsible for keeping a complex and geographically distributed hardware infrastructure running smoothly and maps are essential (see Figure 1) (Koutsofios *et al*. 1999, Wei *et al*. 2000). As a *New York Times* story noted on the huge stress on the US telecommunications systems immediately following the attacks of the 11th September 2001, "*By watching computerized maps of the United States, [operators] can tell in an instant whether there are any jams in long-distance traffic*." (Guernsey, 2001).

Figure 1: View of AT&T's large NOC with large wall displays showing network maps.
(Source: Wei et al. 2000, page 2)

However, the detailed network monitoring maps and tools used by operators in NOCs are not made public for reasons of security and commercial confidentiality. Also, most of these maps are not designed as general purpose maps that can be read by the general-public. Instead, they are specialized management tools that require skilled interpretation. That said, some Internet networks, particularly those serving the research and education communities, do make summary network performance data publicly available using map interfaces. These interfaces are popularly referred to as 'network weather maps'. These maps represent public-spirited information dissemination tools, providing network customers (usually universities and labs) with useful information, especially to identify trouble spots, as well as having a marketing function (see next section).

Below are two examples of network weather maps – the Abilene network in the US (Figure 2) and NORDUnet serving Scandinavia (Figure 3). The maps are updated frequently (for example the Abilene map is updated every five minutes), allowing users a 'peak inside' the network. Both maps provide a summary of overall network performance with links colour coded by their traffic flows, but importantly they also provide an interactive, visual interface through which to browse more detailed performance statistics available as tables and statistical charts (accessed by clicking on links on the map).

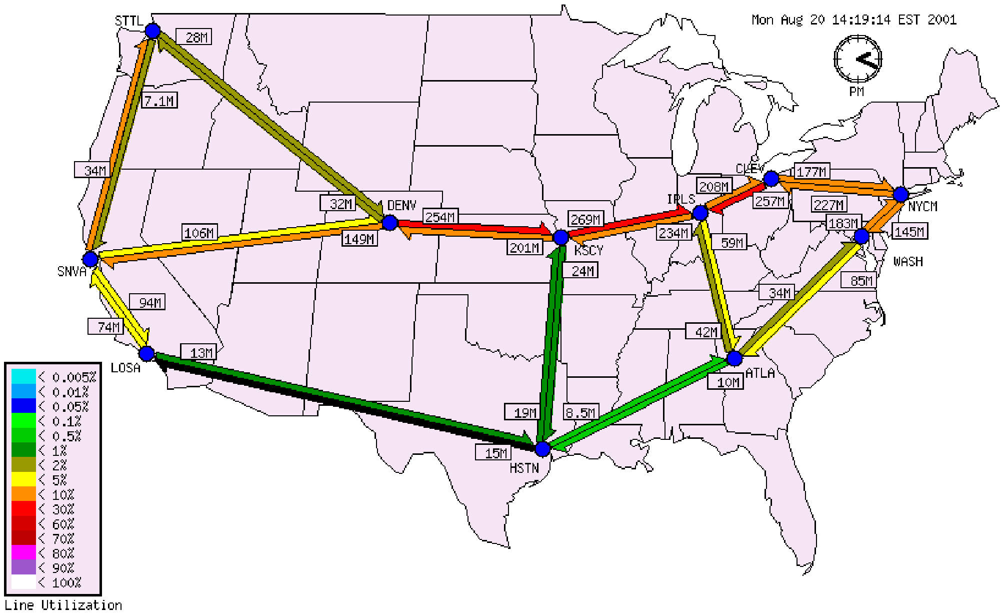


Figure 2: 'Weather map' of the traffic load on the core links of the Abilene network.
(Courtesy of the Abilene Network Operations Center, Indiana University, <http://hydra.uits.iu.edu/~abilene/traffic/>)

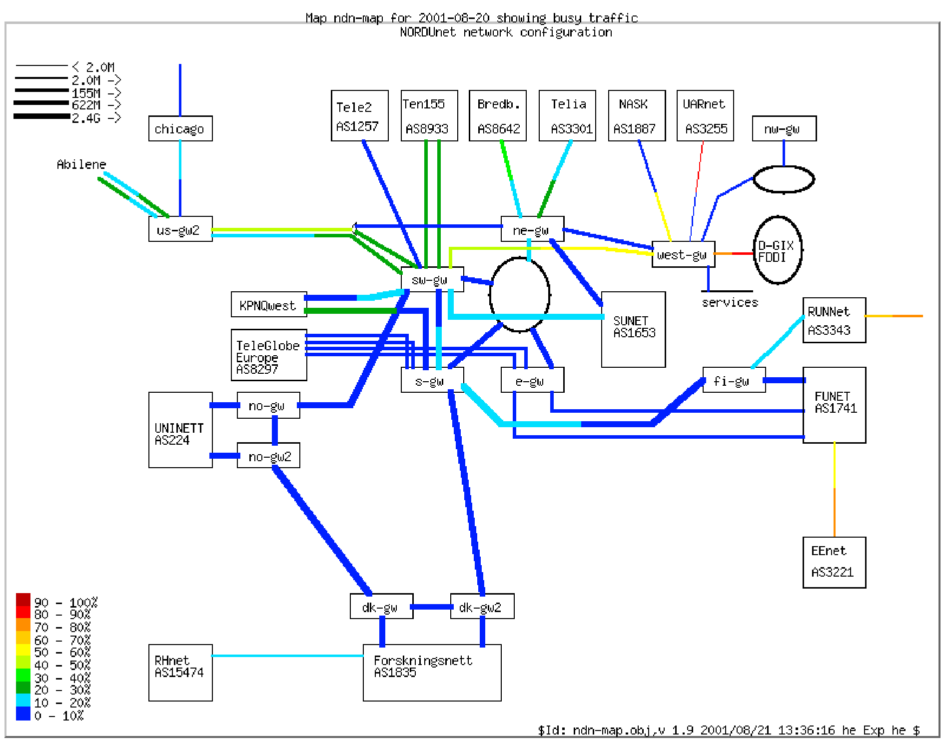


Figure 3: 'Weather map' of network load for the NORDUnet network.
(Courtesy of NORDUnet, <http://www.nordu.net>)

These two maps are also illustrative of the two major cartographic archetypes employed to represent computer networks – showing linkages and nodes either as a logical schematic or on a geographic base with a familiar template of cities and administrative boundaries. These maps can often be highly generalised, with for example the network architecture shown as straight lines, although they are topologically correct (as with conventional subway maps).

In addition to single network maps, there are also some attempts to provide dynamic 'weather' maps of Internet wide performance. For example, Matrix.Net's Internet Weather Report (IWR) [4] presents maps of network latency at many locations across the world using automated large-scale measurement of the Internet taken every 4 hours. Running continuously since 1993, IWR gives one of the few consistent, time-series measurement of the global Internet performance (Quarterman *et al*. 1994). Figure 4 shows a frame from an animated IWR map at the global scale. Forecasts are made six times a day, every day of the year, for over 4,000 Internet sample points all around the world. These forecast measurements are turned into maps with graduated circle symbols representing latency (the larger the circle the longer the delay). In basic terms, small circles on the map show a healthy Internet, while large circles are indicative of poor performance and possible problems.

[4] <http://www.matrix.net/research/weather/>

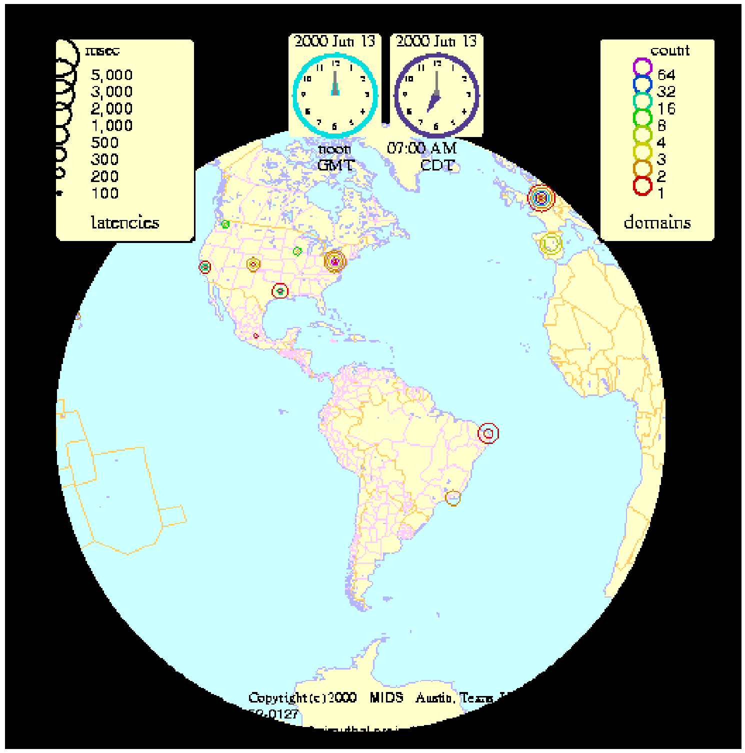


Figure 4: One frame from the animated Internet Weather Map.
(Courtesy of Matrix.Net, <http://www.matrix.net>)

Another method for monitoring network performance are traceroutes, allowing the active monitoring of real-time data routing and to debug connectivity problems. Traceroute is a simple Internet utility which reports the route data packets travel through the Internet to reach a given destination, and the length of time taken to travel between all the nodes along the route (Rickard 1996, Dodge 2000a). Traceroutes reveal the hidden complexity of data flows, traversing ten, twenty or more nodes, seamlessly crossing oceans and national borders and moving through networks often owned and operated by competing companies, to reach a given destination. A typical output of the basic traceroute utility is shown (Figure 5). Each line in the output of traceroute represents a single 'hop' the data takes through the Internet. In this case the data route took 23 hops to reach its destination. Each hop is generally a separate physical node comprising of network switch or router. The approximate locations of this routing hardware can also be plotted on a map to give a geographic traceoute, an example of which is given in Figure 6.

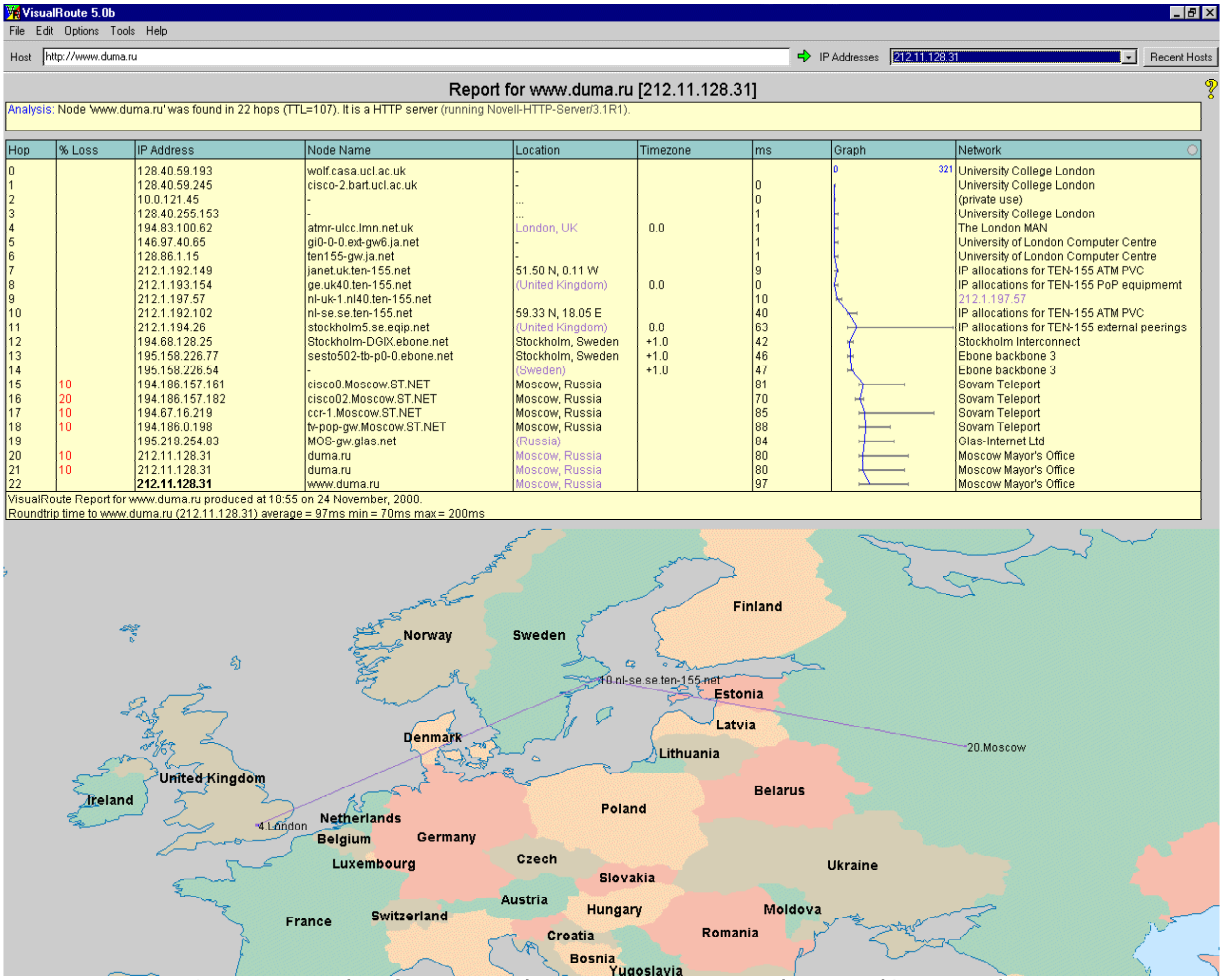
```
Tracing route to walnut.may.ie [149.157.1.115]

over a maximum of 30 hops:

  1   <10 ms    10 ms   <10 ms  209-9-224-225.sdsl.cais.net [209.9.224.225]
  2    30 ms    90 ms    50 ms  172.20.0.1
  3   <10 ms    10 ms    10 ms  fe7-7.core1.mcl.cais.net [63.216.0.77]
  4   <10 ms    20 ms    10 ms  pos3-2.core1.wdc.cais.net [63.216.0.69]
  5    10 ms    10 ms    10 ms  pos3-0.core2.wdc.cais.net [63.216.1.14]
  6    20 ms    30 ms    30 ms  pos5-3.core.pitt.cais.net [63.216.1.62]
  7    40 ms   130 ms    30 ms  pos5-0.core1.pitt.cais.net [63.216.6.13]
  8    50 ms    40 ms    60 ms  pos5-3.core.det.cais.net [63.216.7.58]
  9    40 ms    40 ms    40 ms  pos5-0.core1.det.cais.net [63.216.8.13]
 10    50 ms    70 ms    50 ms  pos5-2.core.chi.cais.net [63.216.8.58]
 11    90 ms    81 ms    70 ms  uunet.a3-0.4.core2.chi.cais.net [63.216.9.65]
 12    60 ms    70 ms    60 ms  0.so-5-1-0.XL1.CHI2.ALTER.NET [152.63.67.242]
 13    50 ms    60 ms    80 ms  0.so-7-0-0.XR1.CHI2.ALTER.NET [152.63.67.130]
 14   150 ms    60 ms   121 ms  0.so-3-0-0.TR1.CHI2.ALTER.NET [152.63.15.86]
 15    80 ms   100 ms    70 ms  126.at-4-0-0.IR1.NYC9.ALTER.NET [152.63.1.121]
 16    80 ms    70 ms    90 ms  so-1-0-0.IR1.NYC12.ALTER.NET [152.63.23.62]
 17   131 ms   140 ms   190 ms  so-5-0-0.TR1.LND9.Alter.Net [146.188.15.49]
 18   130 ms   141 ms   170 ms  pos0-1.cr2.dub2.gbb.uk.uu.net [158.43.253.58]
 19   141 ms   120 ms   160 ms  ge0-0-0.gw4.dub2.gbb.uk.uu.net [158.43.152.6]
 20   130 ms   151 ms   120 ms  158.43.111.102
 21   161 ms   180 ms   140 ms  Oswald-f1-1.dublin.core.hea.net [193.1.195.137]
 22   151 ms   200 ms   170 ms  Uther-g1-0-0.dublin.core.hea.net [193.1.195.242]
 23   211 ms   180 ms   190 ms  nuim-kinnegad.atm.link.hea.net [193.1.194.22]
 24   161 ms   200 ms   160 ms  walnut.may.ie [149.157.1.115]

Trace complete.
```

Figure 5: Traceroute listing of real-time Internet route taken by data between a PC in the Washington DC area and a web server located just outside Dublin, Ireland.



VisualRoute 5.0b

File Edit Options Tools Help

Host http://www.duma.ru IP Addresses 212.11.128.31 Recent Hosts

Report for www.duma.ru [212.11.128.31]

Analysis: Node 'www.duma.ru' was found in 22 hops (TTL=107). It is a HTTP server (running Novell-HTTP-Server/3.1R1).

Hop	% Loss	IP Address	Node Name	Location	Timezone	ms	Graph	Network
0		128.40.59.193	wolf.casa.ucl.ac.uk	-			0 321	University College London
1		128.40.59.245	cisco-2.bart.ucl.ac.uk	-		0		University College London
2		10.0.121.45	-	...		0		(private use)
3		128.40.255.153	-	...		1		University College London
4		194.83.100.62	atmr-ulcc.lmn.net.uk	London, UK	0.0	1		The London MAN
5		146.97.40.65	gi0-0-0.ext-gw6.ja.net	-		1		University of London Computer Centre
6		128.86.1.15	ten155-gw.ja.net	-		1		University of London Computer Centre
7		212.1.192.149	janet.uk.ten-155.net	51.50 N, 0.11 W		9		IP allocations for TEN-155 ATM PVC
8		212.1.193.154	ge.uk40.ten-155.net	(United Kingdom)	0.0	0		IP allocations for TEN-155 PoP equipmemt
9		212.1.197.57	nl-uk-1.nl40.ten-155.net			10		212.1.197.57
10		212.1.192.102	nl-se.se.ten-155.net	59.33 N, 18.05 E		40		IP allocations for TEN-155 ATM PVC
11		212.1.194.26	stockholm5.se.eqip.net	(United Kingdom)	0.0	63		IP allocations for TEN-155 external peerings
12		194.68.128.25	Stockholm-DGIX.ebone.net	Stockholm, Sweden	+1.0	42		Stockholm Interconnect
13		195.158.226.77	sesto502-tb-p0-0.ebone.net	Stockholm, Sweden	+1.0	46		Ebone backbone 3
14		195.158.226.54	-	(Sweden)	+1.0	47		Ebone backbone 3
15	10	194.186.157.161	cisco0.Moscow.ST.NET	Moscow, Russia		81		Sovam Teleport
16	20	194.186.157.182	cisco02.Moscow.ST.NET	Moscow, Russia		70		Sovam Teleport
17	10	194.67.16.219	ccr-1.Moscow.ST.NET	Moscow, Russia		85		Sovam Teleport
18	10	194.186.0.198	tv-pop-gw.Moscow.ST.NET	Moscow, Russia		88		Sovam Teleport
19		195.218.254.83	MOS-gw.glas.net	(Russia)		84		Glas-Internet Ltd
20	10	212.11.128.31	duma.ru	Moscow, Russia		80		Moscow Mayor's Office
21	10	212.11.128.31	duma.ru	Moscow, Russia		80		Moscow Mayor's Office
22		**212.11.128.31**	www.duma.ru	Moscow, Russia		97		Moscow Mayor's Office

VisualRoute Report for www.duma.ru produced at 18:55 on 24 November, 2000.
Roundtrip time to www.duma.ru (212.11.128.31) average = 97ms min = 70ms max = 200ms

Figure 6: An example of a geographic traceroute using the VisualRoute utility. The Internet route is between London and Russian Duma website in Moscow.

The physical infrastructure of the Internet is largely invisible to the casual observer being built into the fabric of buildings and under roads. Nevertheless it has to be installed in the first place and subsequently maintained and upgraded. Highly detailed large scale maps and plans of the physical infrastructure are routinely used for keeping track of network architecture, for example schematics of the exact cable routes are needed by the engineers who actually drill the holes and dig up the roads. Here, CAD, AM/FM and cable management systems that utilize spatial databases and map-layer representations are widely used (Fry 1999). However, these maps are generally not available for public consumption.

Maps For Internet Marketing

A large number of infrastructure maps of the different Internet networks have been produced primarily for the purposes of marketing. Indeed, a cursory examination of most any ISP websites will reveal 'high-gloss' marketing maps. This is, perhaps, not surprising as maps have long been created in the service of marketing and promotion (Tyner 1982, Monmonier 1991). Geographic maps can be seen in some senses as the natural visual representation of transportation and communications networks, able to effectively show potential customers how a particular network could expedite their travel needs. As a consequence, there is a long (dis)honourable tradition of promotional maps being used to highlight the advantages of the latest transportation network such as canals, oceanic shipping lines, railroads, highways and of course airlines (cf. Ackerman 1993, Fleming 1984).

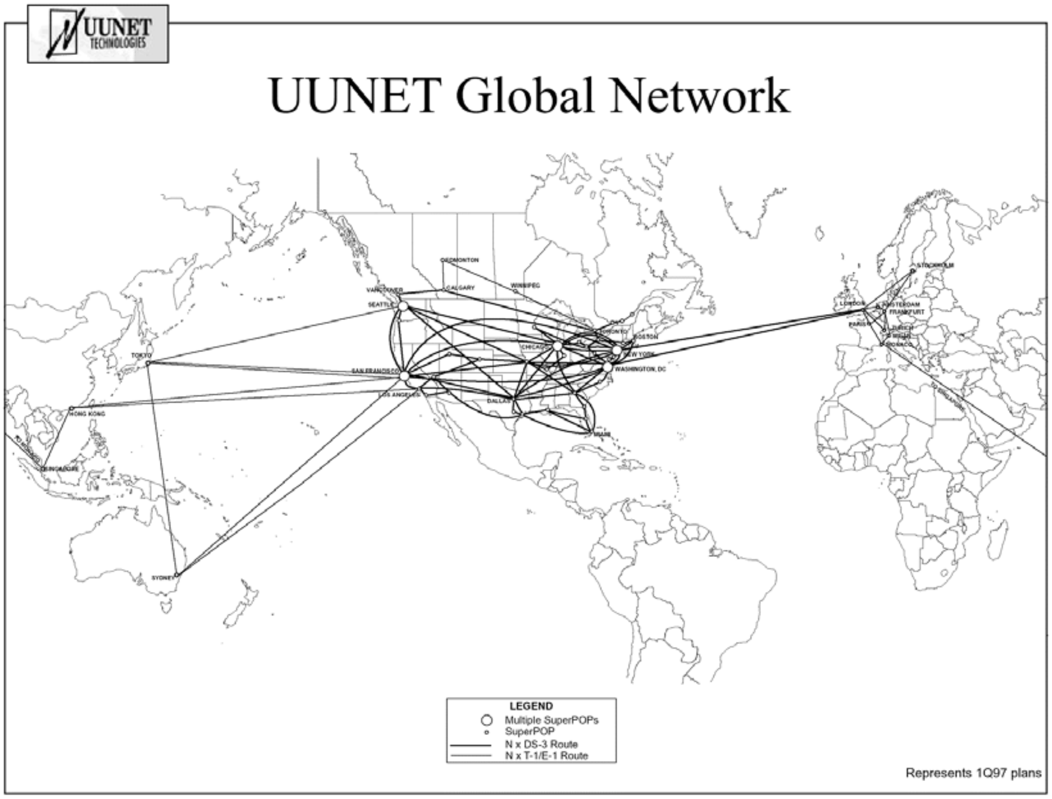
Given that the provision of Internet network services is a highly competitive business, dominated by large corporations many of whom operate globally, effective marketing is a vitally important activity. Here, maps are employed to provide a selective and positive view of a network, emphasizing the its extent (e.g. demonstrating the geographic reach of the network, emphasising all the distant places that are linked together) and capabilities (e.g. illustrating the tremendous capacity of the 'pipes' of the network to cope with huge users demands) in order to attract and compete for custom. In many respects Internet network provision is such an intangible commodity that the map is powerful in making it seem more 'real'. The maps generally show a generalized and simplified view of the network, usually in a bright, colorful and visually effecting manner. Most often the maps are drawn on a template of real work geography and have many design commonalities with the airline route maps in the back of in-flight magazines.

While these maps do provide a selective picture, a reflection of what the company wants to emphasize, they also allow academic researchers and others to chart the range and make-up of each companies network, to document different kinds of provision at a range of scales, and importantly to note how this has changed over time. For example, Gorman and Malecki (2000), Moss and Townsend (2000), Wheeler and O'Kelly (1999) have undertaken useful analysis of the geography of Internet network topology based on data gathered, in part, from ISP marketing maps. This can be illustrated in reference to an analysis of UUNet's (part of Worldcom) infrastructure. Growing at over self-report rate of 1000 per cent per year [5] a longitudinal study of their maps at a variety of scales allows us to see the company's strategy for delivering infrastructure services and to project the likely consequences this strategy on issues such as the digital divide, urban-regional restructuring, local and regional economic development, and so on (see Figure 7). What is clear from these maps is that UUNet is a global supplier of network services, but that the network is confined to the three main pan-regional trading zones (North America, Europe, Asia), and to the principle cities (hubs) in these regions who are most likely to hold potential customers. Lower level cities have lower capacity linkages, and other potentially less profitable areas and cities are bypassed all together (e.g. most of middle America).

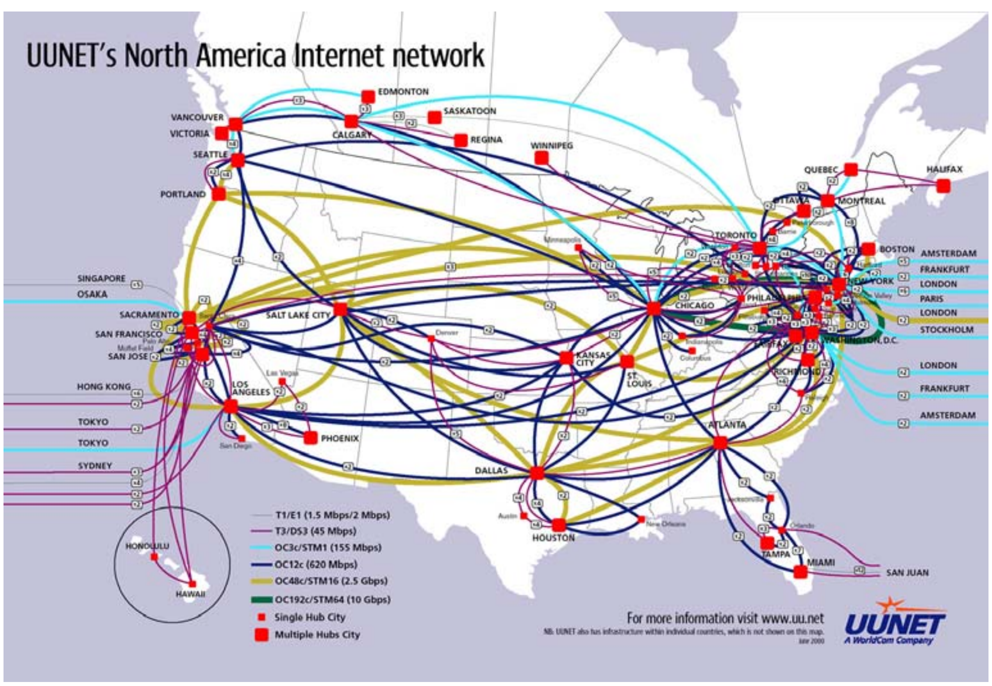
[5] The 1000 per cent figure might well be apocryphal and has been disputed, see for example Odlyzko (2000).

Figure 7: Example marketing map showing the Internet network of UUNET, one of the largest providers. (a) UUNET global network as of first quarter 1997, (b) US network from June 2000, (c) the UK and Ireland, February 2001. *(Courtesy of UUNET, <http://www.uu.net/>)*

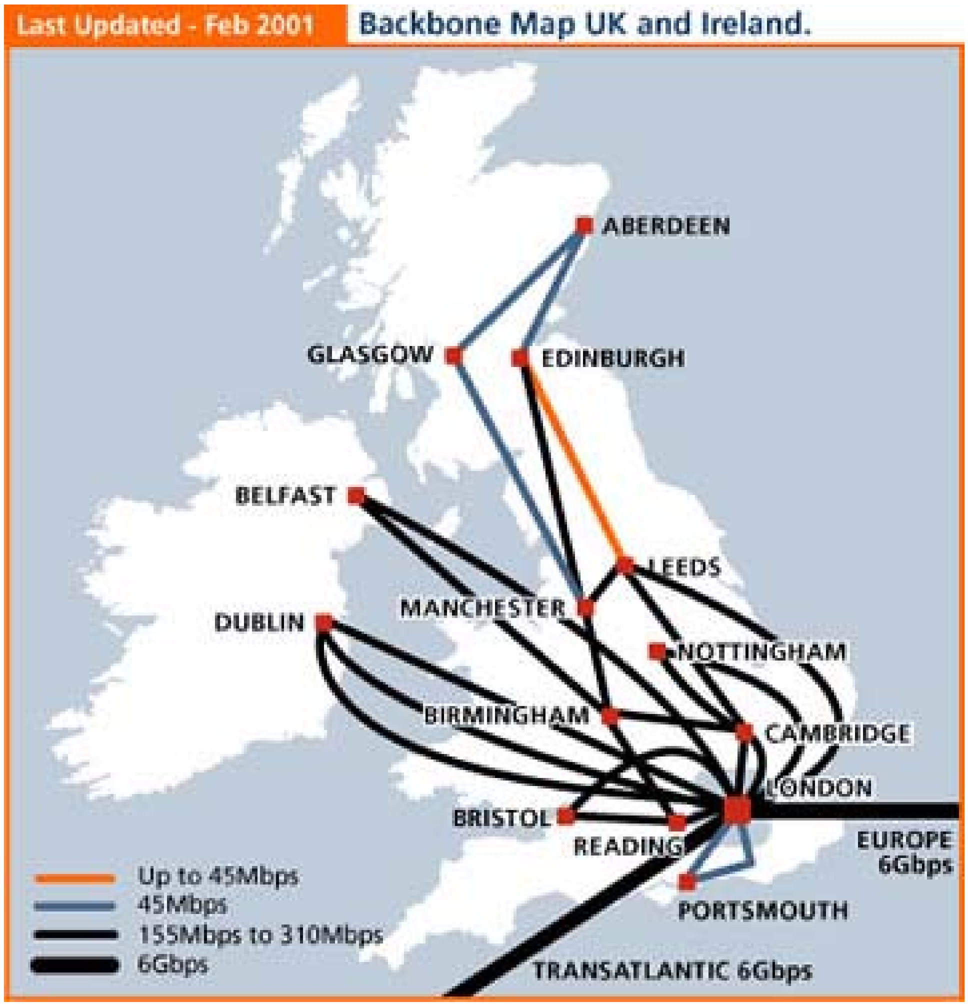
(a)



(b)



(c)



Maps For Strategic Planning And Policy

There is a long history of using maps as instruments of planning and policy. Maps have been key strategic devices used in planning and implementing urban and regional development, plotting military strategy and the conquest of new lands, and legally contesting land ownership and use. Unsurprisingly then they are also being used in the short and long term strategic planning of Internet development by commercial enterprises, governmental, quasi-governmental, and other interested bodies (e.g. the Internet Society). That said, the extensiveness and impact of their use is difficult to gauge quantitatively. While we give several examples where maps have been used, we suspect that their full potential is not yet being realized (this is based on the fact that we could locate relatively few examples of where maps had been used as key analytical resources). This under-usage is, we suspect, because there is a perception that the Internet is somehow non-material in substance, due to its mode of interaction, and the relative invisibility of infrastructure. In addition, data to create useful maps is often closely guarded by service providers and its use restricted from the public domain, and other forms of data generation are costly and technically difficult. In order to structure our analysis we have divided our discussion into two related themes. The first concerns the planning and development of infrastructure, the second, regional development, the attraction of inward investment, and the monitoring and addressing of inequalities.

At one level, maps have been used in the planning, development and expansion of network infrastructure at a variety of scales from individual buildings to global networks. Planning the optimum topology for a communications network to efficiently interconnect geographically dispersed locations is an exacting task. Maps help visualize complex network topologies and how new configurations will look and operate. Figure 8 is a 'back of the envelope' hand drawn sketch map from the early planning of ARPANET[6], plotted by the project manager Larry Robert in the late 1960s. It shows the projected topological routing of the fledgling Internet between nodes. Figure 9 shows the fibre-optic cable routing in downtown Philadelphia, a city home to 270 technology firms in 2001, 60 per cent of whom were located in the center city, requiring high-speed Internet connections. Many of these companies are members of ePhiladelphia Technology Alliance an organization dedicated to creating and fostering a vibrant

[6] ARPANET pioneered wide-area packet-switching networking and laid much of the foundations of the Internet we know it today, developing both the technical and social infrastructure of internetworking (Abbate 1999, Hafner and Lyon 1996). It was initially conceived as a method to link several incompatible computer systems located at various points across the USA so that resources could be shared and was funded by the US military, through the ARPA agency.

technology community within the city. By mapping companies in relation to cable-routing the city can adequately provide network connections and plan extensions that will hopefully attract in new customer. At a larger-scale, countries are crisscrossed by many interconnected networks. An important function for ISPs is to easily and efficiently interconnect and exchange local traffic at neutral peering points. Figure 10 shows two examples of national-level maps tracking the Internet infrastructure in the Republic of Korea produced by Korean Network Information Center, based in Seoul [7]. Analysts at KRNIC have produced a whole series of maps over the past five years using topological graphs representations. The two maps clearly reveal the tremendous growth in the number of ISPs, their interconnections and capacity of links within and external to Korea. The maps are valuable policy and research resource creating a census of the growing complexity of the links between ISPs and their capacity.

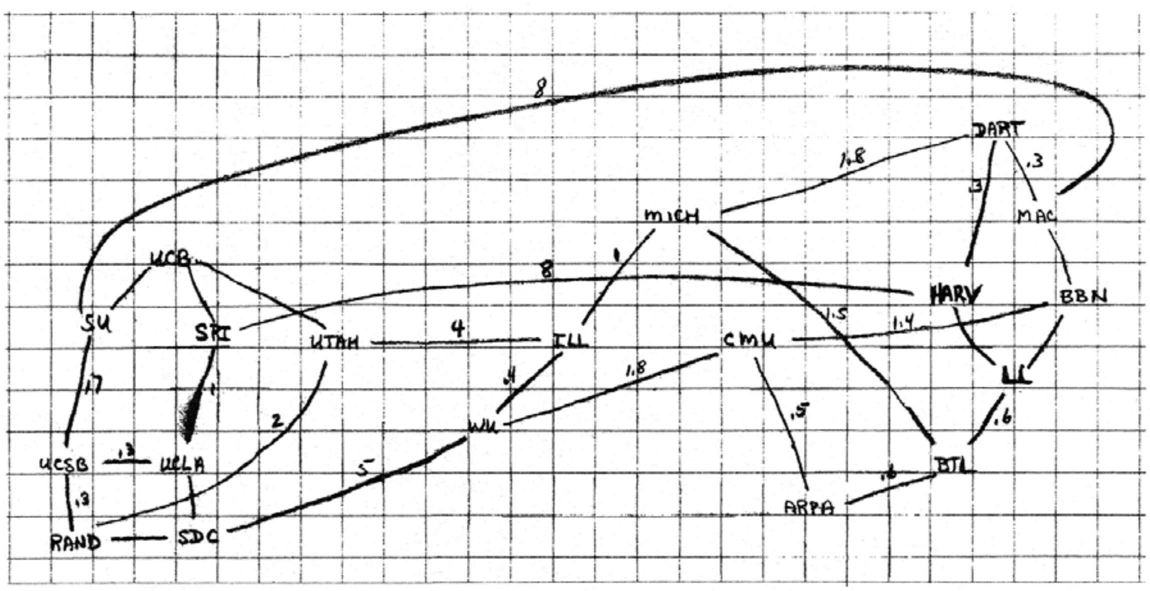


Figure 8: A 'back of the envelope' style sketch map for network topology planning.
(Courtesy of Hafner and Lyon 1996, page 50.)

[7] <http://stat.nic.or.kr/english/network.html>

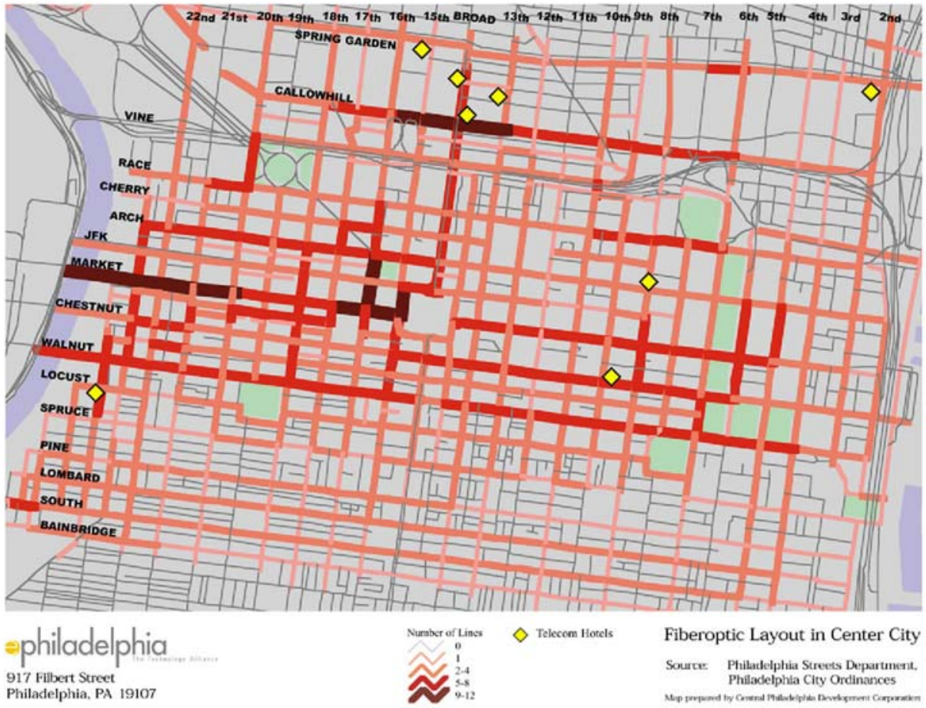
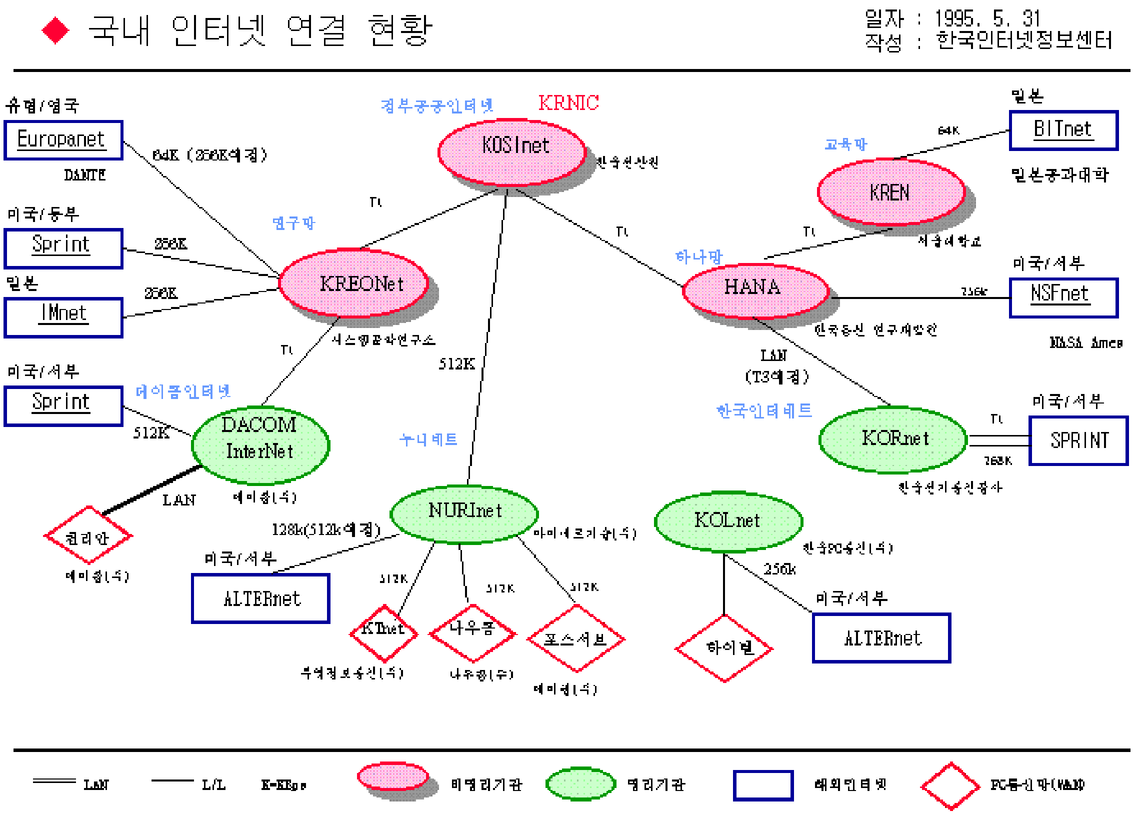


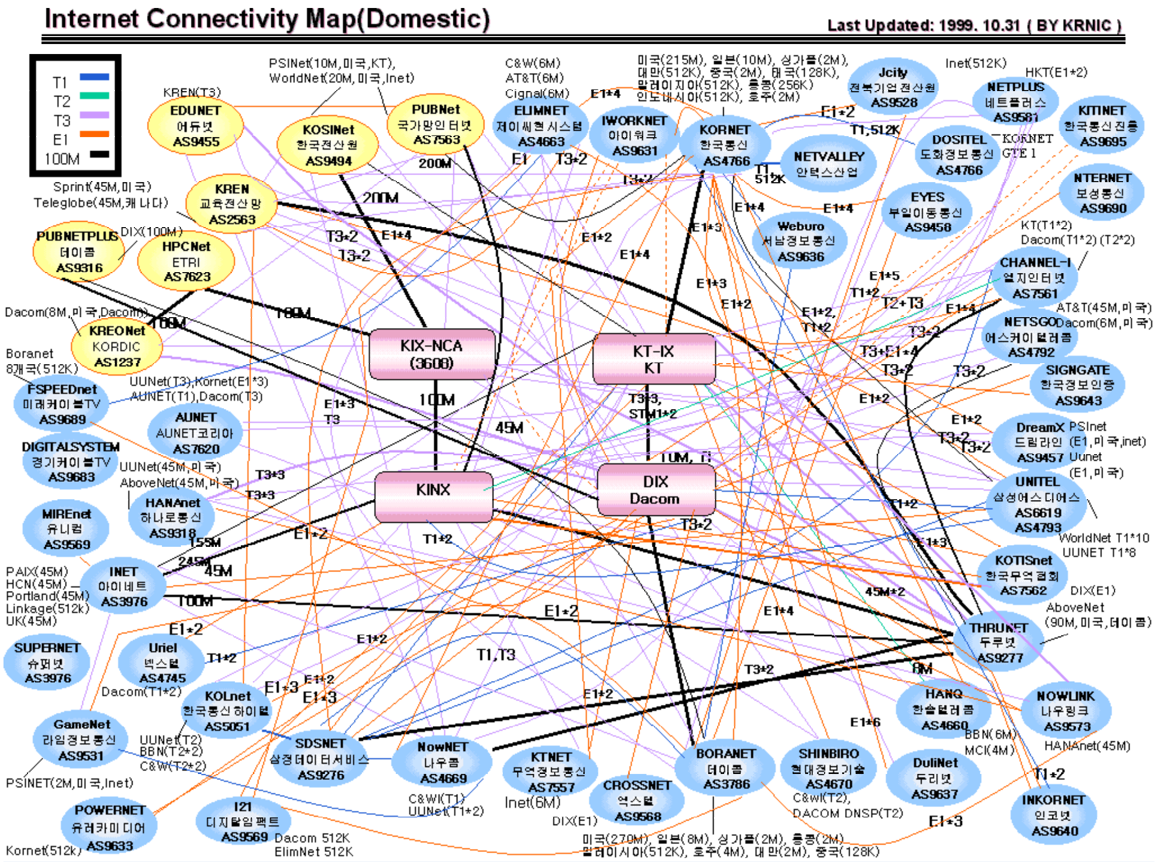
Figure 9: Fibre-optic routes in central Philadelphia.
(Courtesy of Central Philadelphia Development Corporation, http://www.centercityphila.org/it.html)

(a)



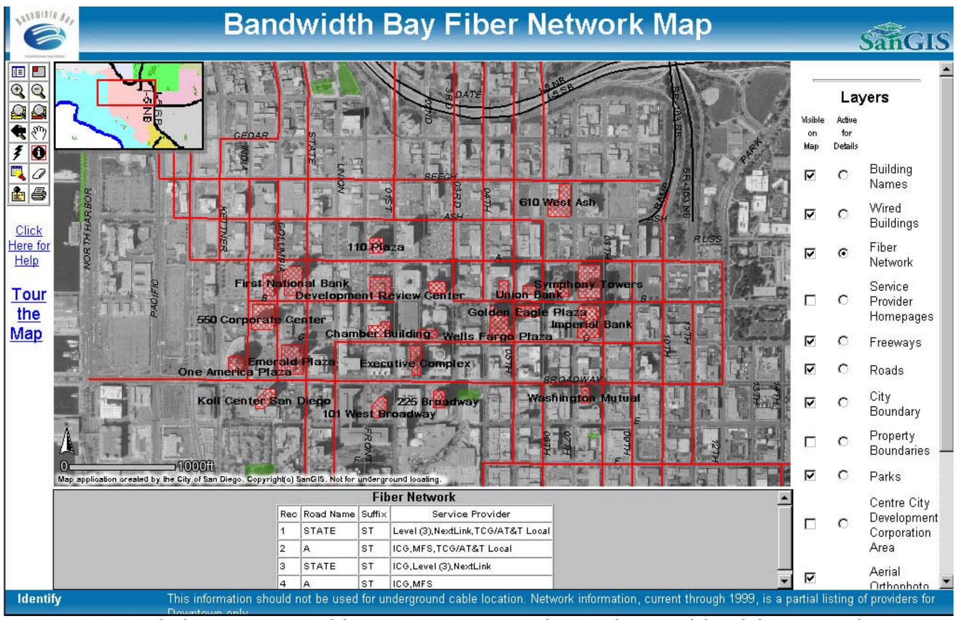
국내 인터넷 연결 현황
일자 : 1995. 5. 31
작성 : 한국인터넷정보센터
유럽/영국
Europanet
DANTE
64K (256K예정)
미국/동부
Sprint
256K
일본
IMnet
256K
미국/서부
Sprint
512K
정부공공인터넷
KRNIC
KOSInet
연구망
KREONet
시스템공학연구소
T1
데이콤인터넷
DACOM InterNet
데이콤(주)
LAN
천리안
데이콤(주)
512K
누니네트
NURInet
128k(512k예정)
미국/서부
ALTERnet
512K
KTnet
나우콤
포스서브
데이콤(주)
나우콤(주)
교육망
KREN
서울대학교
일본
BITnet
64K
일본공과대학
하나망
HANA
한국통신 연구개발원
미국/서부
NSFnet
NASA Ames
LAN
(T3예정)
한국인터네트
KORnet
미국/서부
SPRINT
T1
한국전기통신공사
KOLnet
256k
미국/서부
ALTERnet
하이텔
LAN
L/L
비영리기관
영리기관
해외인터넷

(b)



Figures 10: Topology maps of ISP interconnections in the Republic of Korea
from (a) May 1995 and (b) October 1999.
(Courtesy of the Korean Network Information Center,
< http://www.nic.or.kr/ >)

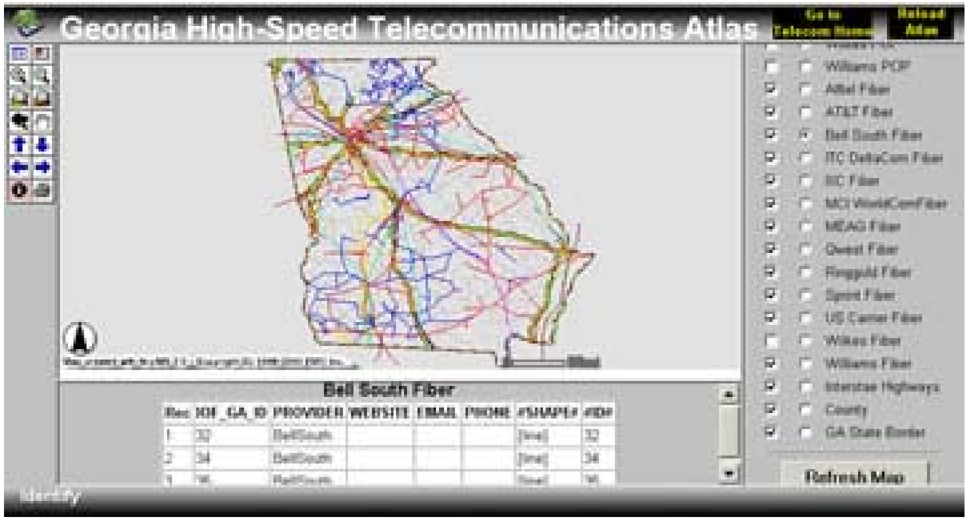
At a second level, maps have been employed in the strategic planning and implementation of regional development and in monitoring and addressing inequalities, the so-called digital divide, between places. Again, the data relates to several scales from intra-urban to global. As widely documented, cities are increasingly becoming competitive enterprises, vying to attract investment of the high-tech sector (Graham and Marvin 2001). Here, the 'where' of infrastructure is important, with decisions about structural investment tied into a city's economic future. Here public-private partnerships between city government, commercial ICT infrastructure companies, a range of economic and public policy consultancies, and local development and community groups seek to maximise their connectivity within optimal constraints (e.g. profit). Maps are a potentially important tool for illustrating high-capacity internet infrastructure to potential inward investors and encouraging economic development. Examples include the 'Bandwidth Bay Fiber Network Mapping' [8] by the City of San Diego (Abouna 2001; Figure 11) and the 'Georgia High-Speed Telecommunications Atlas' [9] in the state of Georgia, USA (French and Jia 2001; Figure 12).



Rec	Road Name	Suffix	Service Provider
1	STATE	ST	Level (3),NextLink,TCG/AT&T Local
2	A	ST	ICG,MFS,TCG/AT&T Local
3	STATE	ST	ICG,Level (3),NextLink
4	A	ST	ICG,MFS

Figures 11: Map of the Internet fibre-optic networks and wired buildings in downtown San Diego from the Bandwidth Bay system.
(Courtesy of San Diego Geographical Information Source, <http://www.bandwidthbay.org/main.htm>)

[8] <http://www.bandwidthbay.org/main.htm>
[9] <http://maps.gis.gatech.edu/telecomweb/index.html>



Figures 12: Map of the commercial networks infrastructure in Georgia, USA.
(Courtesy of Center for Geographic Information Systems, <http://maps.gis.gatech.edu/telecomweb/index.html>)

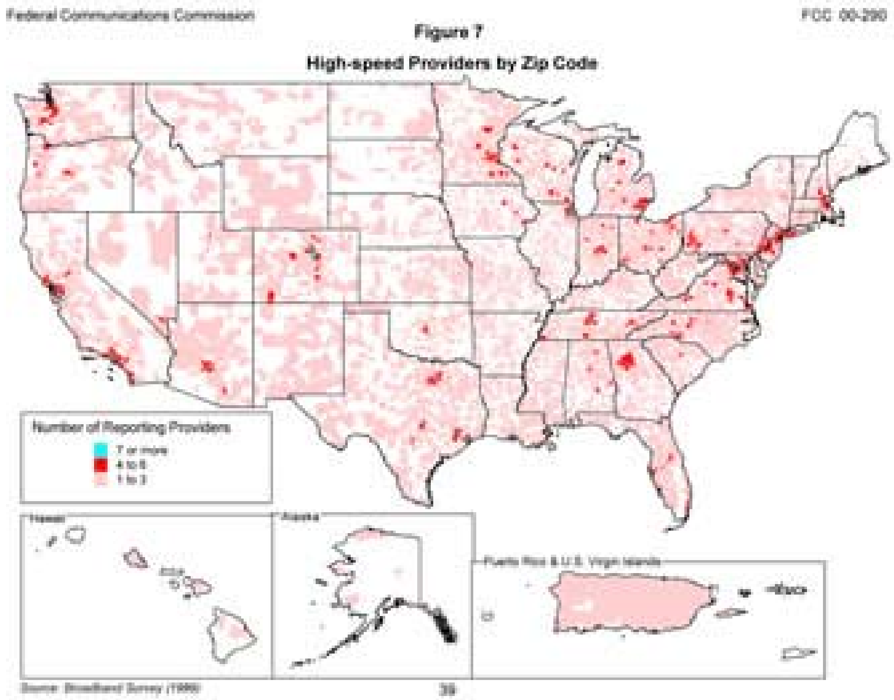
As well as seeking ways to gain competitive advantage (exploiting the differences between cities), paradoxically these data are also being analyzed for ways to close the digital divide within cities. Indeed, it is a policy of most Western governments at this point to try and ensure widespread access to the Internet so that communities, at all scales – local, regional, national - are not left too far behind. For example, two federal US schemes designed to facilitate connecting disadvantaged communities to the Internet are the Community Technology Center (CTC) programs (Office of Adult and Vocational Education, Department of Education) and Technology Opportunity program (Office of Commerce)[10]. These are supplemented by a wide range of other programs at state and city level. For example, the Federal Communications Commission (FCC) (the US telecom regulator) is concerned with issues of access and equity for different communities. Public policy makers obviously recognize that wiring areas requires considerable infrastructure investment on the part of commercial providers, with the incentive to concentrate on those areas most likely to return an operating profit. Consequently regulators are

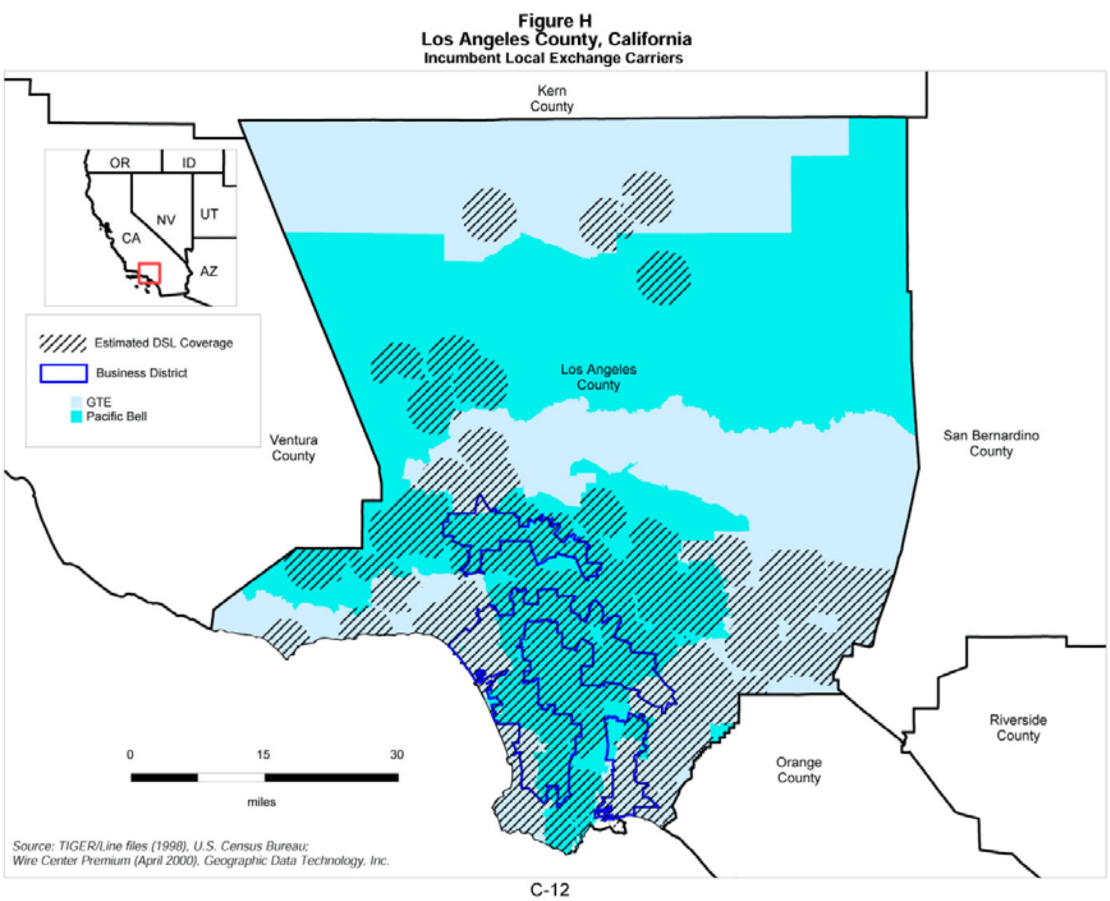
[10] <http://www.ed.gov/offices/OVAE/CTC/>, <http://www.ntia.doc.gov/otiahome/top/>

concerned that planned high-speed Internet delivery systems are available, at affordable costs, to all members of a community, in particular, lower income communities or those in more sparsely populated rural areas. Clearly, here, the geography of access is crucial and one strategy open to regulators to make visible inequalities 'on the ground' is to make use of maps which show spatial patterns of broadband Internet availability. Figure 13 provides two examples, at different scales, from a recent Federal Communications Commission report on broadband Internet access. The first map shows the number of broadband providers for zipcode areas across the whole of the US, while the second map focuses just on the local geography of DSL coverage in Los Angeles county, California.

These maps were part of a large report on the FCC regulatory monitoring of providers to insure that they meet the provision of the 1996 Telecommunications Act to encourage the deployment of advanced telecommunications capability to all Americans in a reasonable and timely fashion. The general conclusion of the report, supported by the tables and maps, was that commercial providers were generally meeting targets with 59% of the US zip codes (which represent 91% of the resident population) showing evidence of high-speed Internet access. However, they also issued one crucial caveat:

> "… the data support the troubling conclusion that market forces alone may not guarantee that some categories of Americans will receive timely access to advanced telecommunications capability. We identify certain categories of Americans who are particularly vulnerable to not having access to advanced services. These include low-income consumers, those living in sparsely populated areas, minority consumers, Indians, persons with disabilities and those living in the U.S. territories." (FCC 2000, page 6)





Figures 13: Maps of broadband provision in (a) the US and (b) central Los Angeles.

(*Courtesy of the Federal Communications Commission, <http://www.fcc.gov/broadband/>)*

In addition, in the US the Census Bureau, the Department of Commerce's National and Information Administration, and the Economics and Statistics Administration generate official statistics on Internet and telecommunications access at national and regional scales that are analyzed for their economic policy potential by a range of groups, including local and state government and commercial companies. For example, the Progressive Policy Institute uses a range of these data in formulating their 'New Economy Index' reports[11]. The self-stated aims of these reports is to "…offers policy makers a framework for economic development strategies aimed at promoting fast, and widely shared economic growth and prosperity." Maps are used prominently throughout the report and Figure 14 shows an example mapping the online population, from *The Metropolitan New Economy Index* (April 2001) for the top 50 metropolitan regions in the US. These are grouped into 4 percentile groups. Other maps in the report rank the regions according to 16 indicators that are used to create an overall index of economic competitiveness in the information economy.

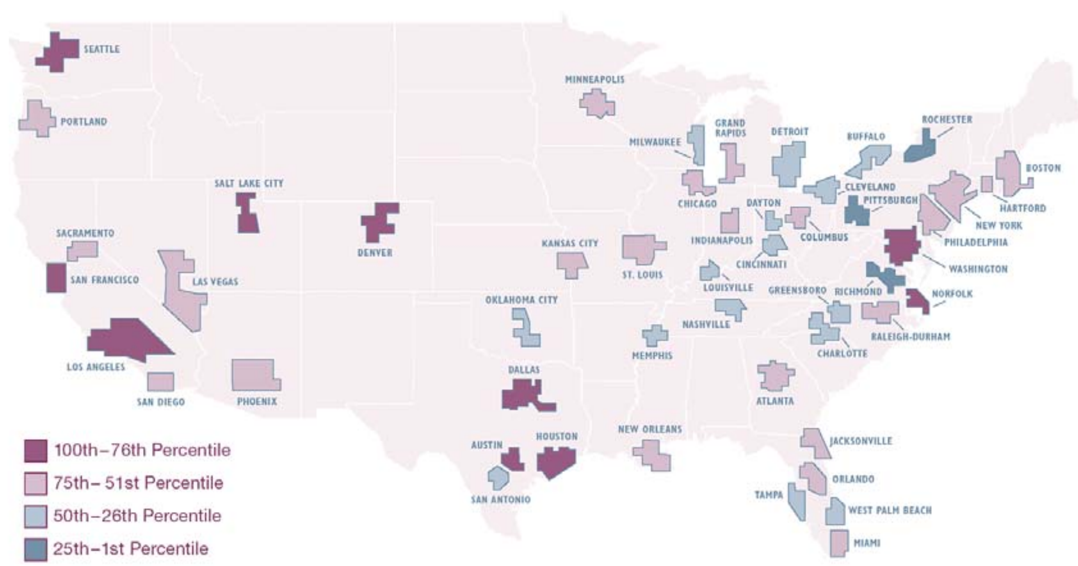


Figure 14: Map of the top 50 US metropolitan areas in terms of online population .
(Courtesy of Progressive Policy Institute, < http://www.neweconomyindex.org/>)

[11] <http://www.neweconomyindex.org/>

Likewise, Mark Krymalowski has been analysing data at the country level, plotting the geographical distribution of .DE domain registrations in Germany[12]. Figure 15 from his research shows the relative number of domains per capita in 2000 for German counties. Krymalowski's analysis and maps of domains were subsequently utilized in analyzing high-tech, economic and regional development (Sternberg 2001). This analysis concluded that the city of Munich and its wider region scored much more heavily in domain name registrations than would be expected simply based on population. This he hypothesized is because this region is the leading zone of IT and multimedia production in Germany. Importantly, Sternberg concludes that, "the Internet does not create new regions but it replicates, at least in Germany, the well-known ranking of regions in terms of high-tech" (Sternberg 2001, page 3). In other words, the information economy is likely to grow most quickly around existing IT hubs, rather than invest in new, potentially cheaper, locations. This clearly has implications to regional development designed to address regional inequalities and attract inward investment given the widespread shift towards an IT-centered service economy.

[12] <http://www.denic.de/doc/DENIC/presse/stats2000.en.html>

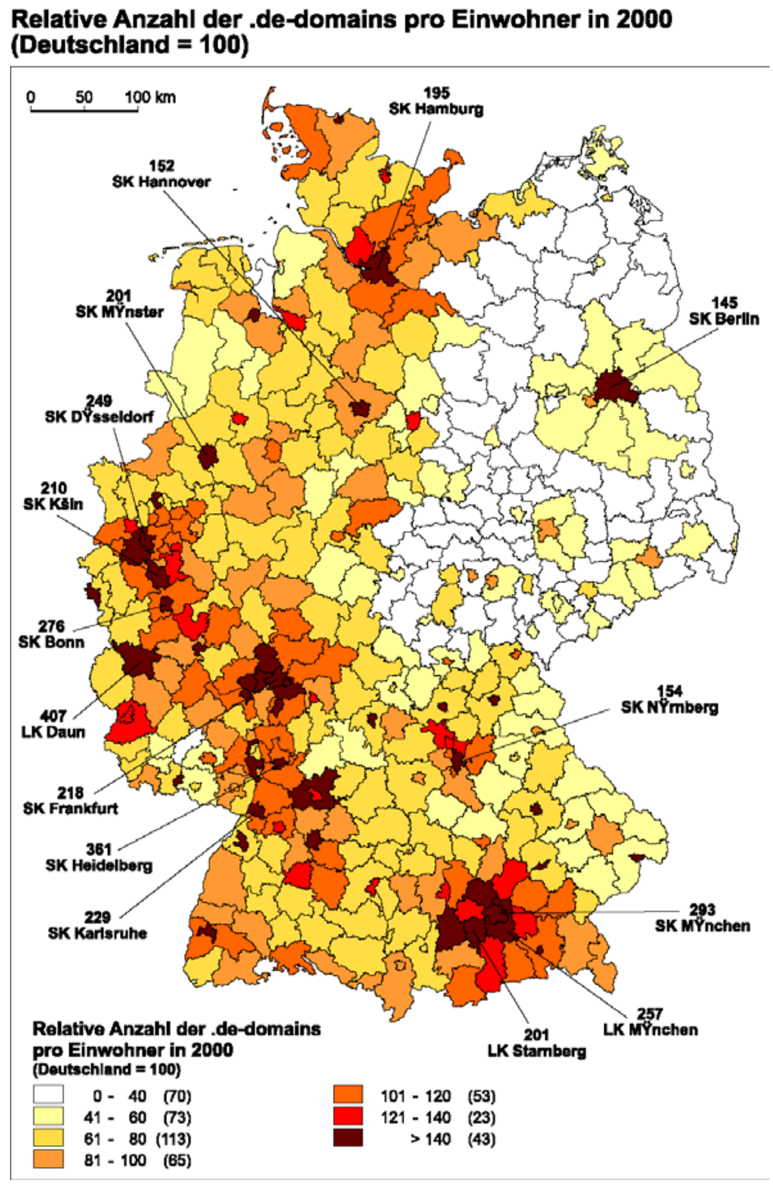
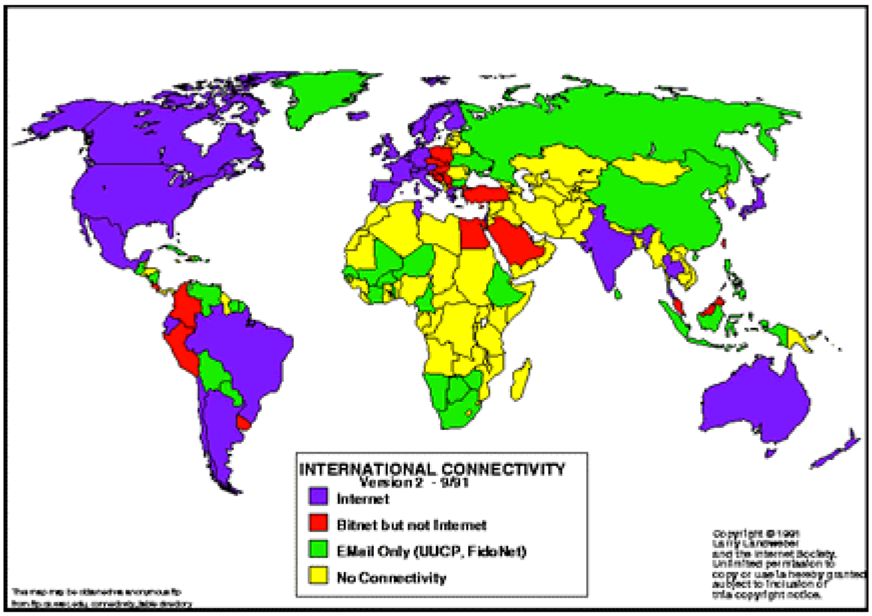


Figure 15: Per capita measure of .DE domains in German counties.
(Courtesy of Mark Krymalowski and DENIC,
<http://www.denic.de>)

These kind of maps when put together in a timeline, form a powerful means for tracking development and for predicting future change. One project that illustrates this is that by Larry Landweber, and several organisations have taken his lead to produce longitudinal maps at different scales (e.g. TeleGeography, and Matrix.Net) which are used by both governments and commercial enterprises to formulate strategies of investment. During the 1990s the

Internet spread across the globe so that by the end of the decade virtually all nations were connected (although the number and capacity of connections still varies greatly). This global diffusion of the Internet was tracked by Landweber and charted in a series of maps (Figure 16) providing a useful baseline census for policy of the spread of international network connectivity (Dodge 2000b). Countries are shaded according to a four-fold classification of network connectivity, with permanent Internet access shown by blue.



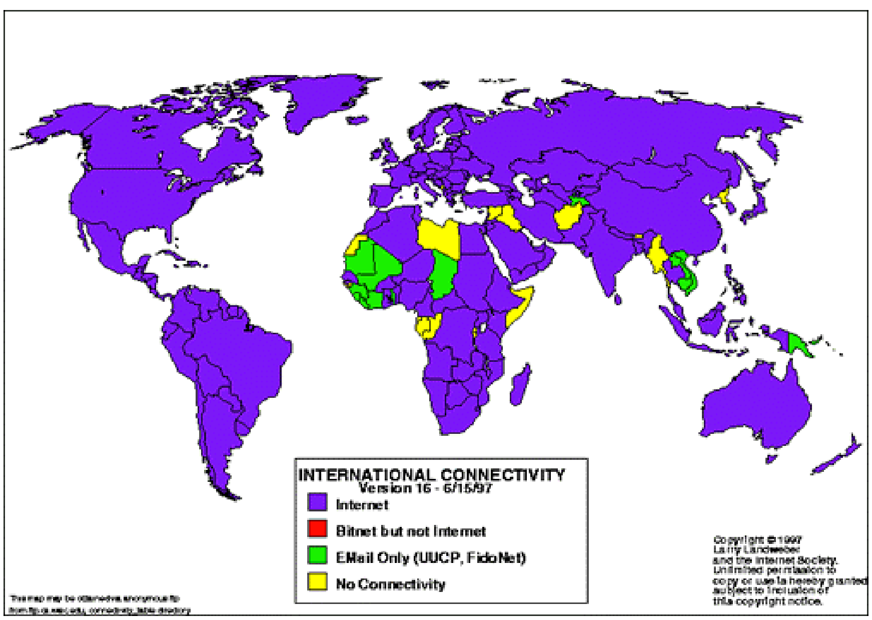


Figure 16: Maps of the global diffusion of the Internet connectivity at the national level by network infrastructure from (a) 1991 and (b) 1997.
(Courtesy of Larry Landweber and the Internet Society, <http://www.cs.wisc.edu/~lhl/maps/>)

These maps provide a partial, but useful, picture of global Internet diffusion through the 1990s. The first map, from 1991, shows that a large number of countries, particularly in the Americas and in Northern Europe, had full Internet connectivity. However, an equally large measure of the world's nations are shaded yellow, indicating that they had no international Internet connectivity. In fact, this category included well over half the nations of the world, though these were clearly concentrated in the less developed regions of Africa and central Asia. By 1997, the majority of the nations of the world were shaded blue. The Internet, as measured by Landweber's survey, was so widespread that the exceptions really stand out. (It was at this point that tracking diffusion at this scale using Landweber's criteria became redundant and, hence, this is the last map in the series). The yellow shaded exceptions were nations suffering from extreme poverty, war and civil conflicts (such as Afghanistan and Somalia) or from external geopolitical isolation (e.g. Libya, North Korea, Burma, Iran and Iraq).

Strategic policy formulation often requires an understanding of the topology and capacity of network infrastructures at the continental and global scales. Figure 17 uses a conventional world map projection to show the global geography of the major high-capacity submarine fibre-optic cables (both operational and planned) that provide vital inter-continental telecommunications infrastructure. In the last decade or so the capacity of new cables systems has been greatly increased by advances in fibre-optical technologies and many billions have been invested (TeleGeography 2001). This has led to a rapid growth in aggregate communication capacity between continents, but much of this new capacity is across the North Atlantic where numerous cables connect the densely ‘wired’ regions of North America and Western Europe. Another vital measure for Internet global policy is understanding the trends in uneven geographic distribution of computers connected. Figure 18 is a proportional symbol map from *Matrix.Net*, a leading Internet monitoring company based in Austin, Texas, shows host computers as of January 2000. The number of hosts is aggregated for major cities and countries and then represented on the map by the coloured circles.

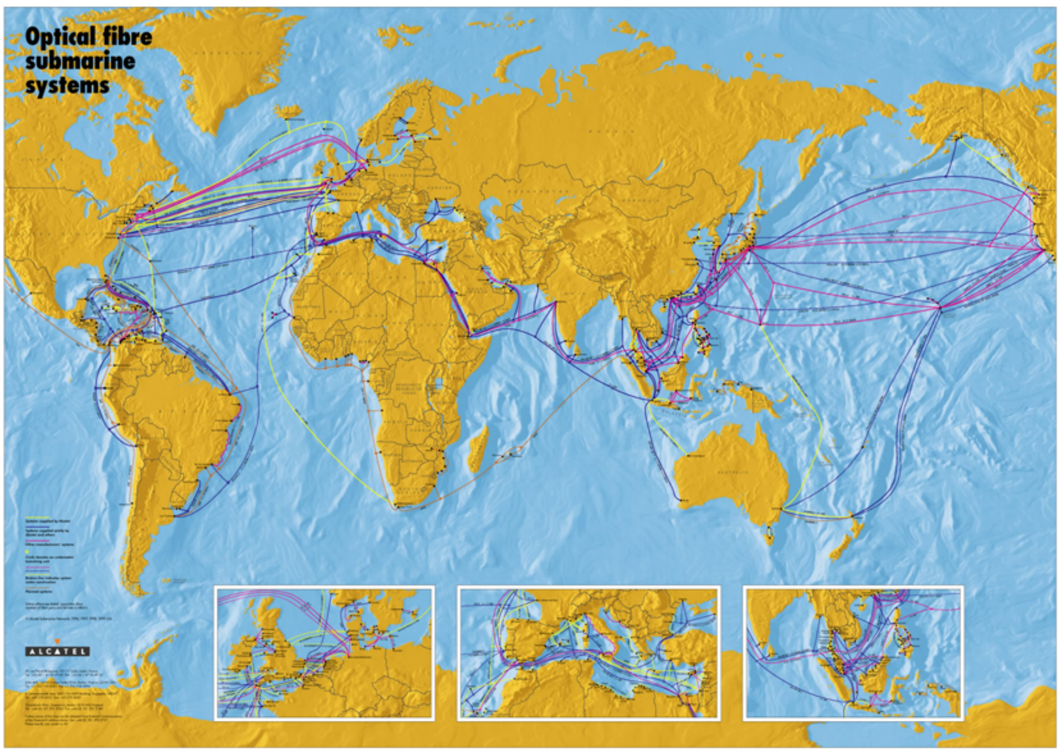


Figure 17: World map of submarine fibre-optic cables.
(Courtesy of Alcatel, <http://www.alcatel.com>)

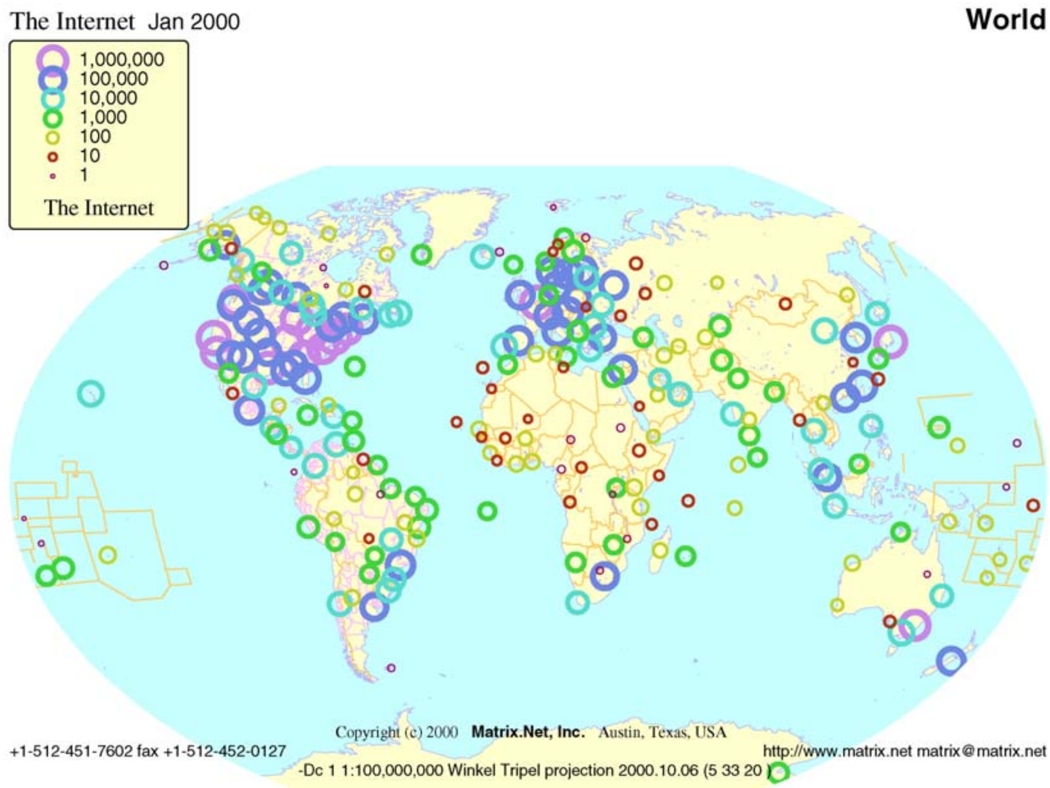


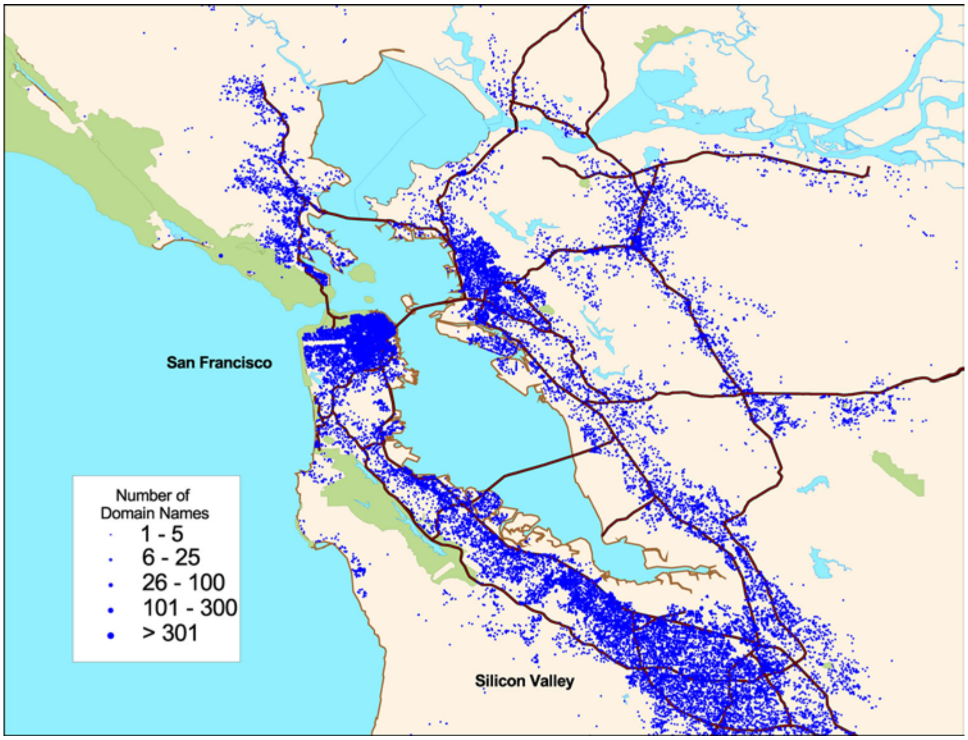
Figure 18: Maps of the number of hosts connected to the Internet, January 2000.
(Courtesy of Matrix.Net, <http://www.matrix.net/>)

Maps like those above clearly reveal global patterns (and inequalities) and therefore provide policy makers with the basic visual census of key Internet infrastructure. It is obvious that the majority of Internet connected host computers are concentrated in relatively few countries in the North, which in turn are well inter-connected with submarine cables. Indeed, the majority of submarine cables (and therefore bandwidth potential) run east-west around the globe rather than north-south. The basic conclusion that can reached from these maps is that the people of the global South, especially on the African continent, are relatively much more poorly served. These type of uneven distributions of the core, high-capacity network links clearly have wider economic and social policy implications, especially for countries on the periphery. It often means that services are more limited and much more expensive (Cukier 1999, Petrazzini and Kibati 1999).

Maps For Academic Internet Analysis

It has been widely argued by academics that the ICTs are transformative technologies that are having significant impacts on social, economic and political life, engendering widespread changes (e.g. Castells 2000, 2001, Graham and Marvin 2001, Kitchin 1998). The process of mapping has been used to comprehend three different sorts of projects aimed at furthering our understanding of these changes in relation to infrastructure: urban-regional restructuring; the digital divide; measuring the Net.

As noted above, maps reveal visually the nature and extent of the 'digital divide' in society. They have therefore been used by a number of academics such Holderness (1998), Moss and Townsend (1997, 2000), Sternberg (2001; see above) and Matthew Zook (2000, 2001) to explore social and economic divides in access to Internet infrastructure at a variety of scales. For example, Matthew Zook has analysed the spatiality of the Internet content production industries in the US through the detailed mapping of the geographic location of domain name registrations at different scales (see Figure 19). Just as postal addresses in the geographic space identify a unique location, domain names perform the same function for the Internet, allowing users to visit the site. Importantly, the geographic location of the owner of these domains can be determined from registration databases, which have a billing postal address, containing zipcodes that can easily be mapped to street-level locations using off-the-shelf GIS software and map data. Figure 19 displays maps for downtown San Francisco using proportional map symbol, with background road and town data to add context. The densest concentration of zipcodes are located in the financial district and 'South of Market' area (famed as the Multimedia Gulch). This mapping led Zook to conclude that the 'Internet industry exhibits a remarkable degree of clustering despite its reported spacelessness' (Zook 1998:18). This approach provides a valuable quantitative measurement for policy analysis on Internet economic activity and revealing where is connected and just as importantly where is not (Zook 2000, 2001).



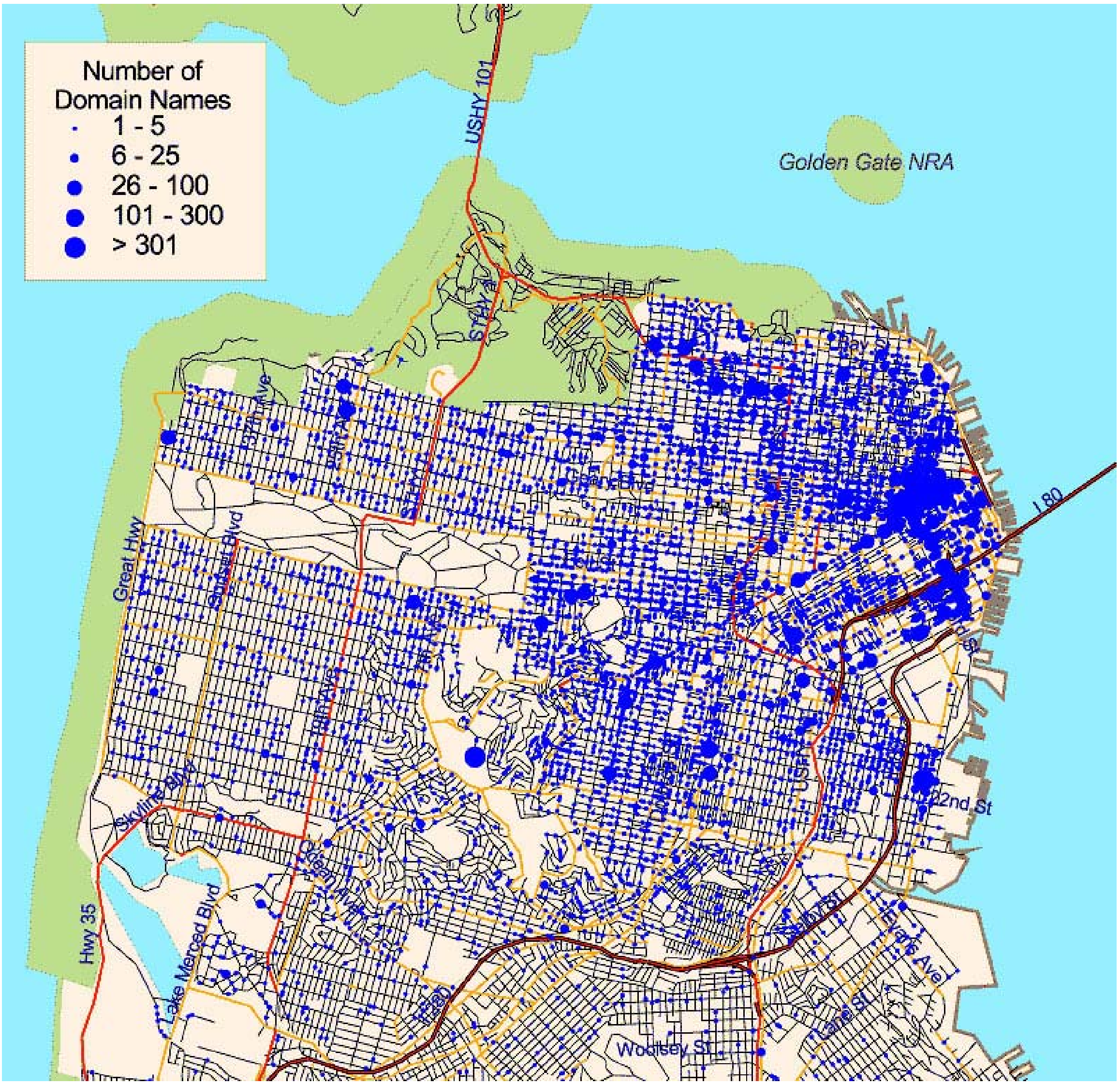


Figure 19: The number of domain names in (a) the Bay / Silicon Valley area of California, (b) San Francisco, 1999.
(Courtesy of Matthew Zook, <http://www.zooknic.com/>)

The final way that maps have been used by academics and commercial research teams is a means by which to display measurements that quantify the extent and use of Internet infrastructure so as to gain a better understanding of its distribution, diffusion and utilisation. Maps have particular appeal because they reveal discernable patterns in large very large datasets and so provide panoramic overviews of where changes are occurring. To date a number of mapping projects have been instigated (see Dodge and Kitchin 2000a, 2001) and here we discuss three in brief.

Figure 20 displays an 'arc map' of Internet traffic flows between fifty nations, from February 1993. The colour, thickness and height of the arcs are used to encode the traffic statistics for particular inter-country routes (Becker *et al.* 1995, Cox *et al.* 1996). The arcs are also partially translucent so as not to completely obscure lines at the back of the map, while their height above the base map is in relation to total volume of traffic flowing over a link. This has the effect of making the most important (high traffic) links, the highest and therefore most visually prominent on the map. In the SeeNet3D application in which the image was generated, the user had considerable interactive control able, for example, to vary the arc height, scaling and translucency. The map could also be rotated and scaled, so that the user can view it from any angle. The map shows that there was significant traffic, in the early 1990s, between three areas of the world, North America to Europe, Europe and Australiasia, and Australiasia and North America, with most traffic crossing the Atlantic. The map does not show all traffic, however, because it is limited to just fifty countries. As such, it portrays a selected image, one that is dominated by developed countries that were the principle nations connected to the Internet in 1993.

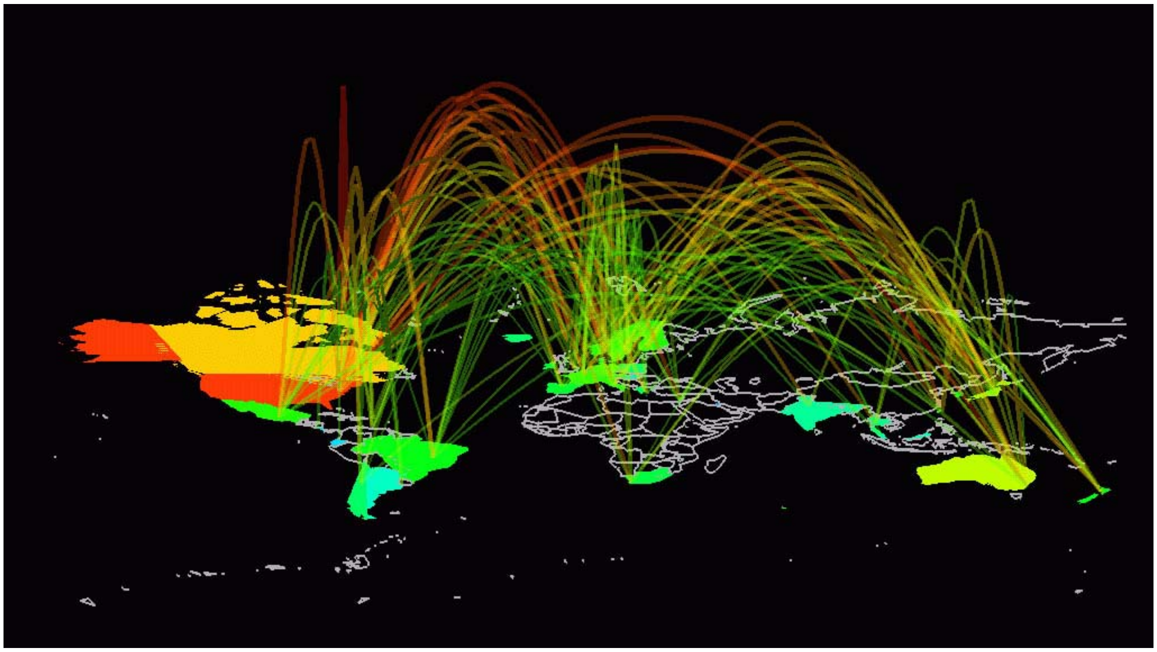


Figure 20: Interactive visualization of Internet traffic in the SEENET3D network analysis application. *(Courtesy of Stephen Eick, Visual Insights)*

Figure 21 is a 3D, interactive geographic visualisation of the Internet MBone network (Munzner *et al.* 1996). The MBone comprises a special set of routes, known as 'tunnels' in technical jargon, which run on top of the ordinary Internet and are used to deliver multicast data. Multicasting is an Internet protocol designed for delivering efficiently a single copy of a chunk of data to many different people. It is especially useful for distributing real-time audio and video. Munzner and her colleagues map these tunnels as arcs on 3D model of the globe, which the user can manipulate to rotate and view from any angle. The line colour and thickness are used to show characteristics of the MBone tunnels, while the height of the arcs above the surface of the globe is a function of distance between the end MBone router nodes. Before their mapping it was very difficult to determine the extent of the MBone infrastructure because they were created by several different organisations and their characteristics were documented using text listings (some seventy-five pages in length in June 1996) from which it was very difficult to determine the topology.

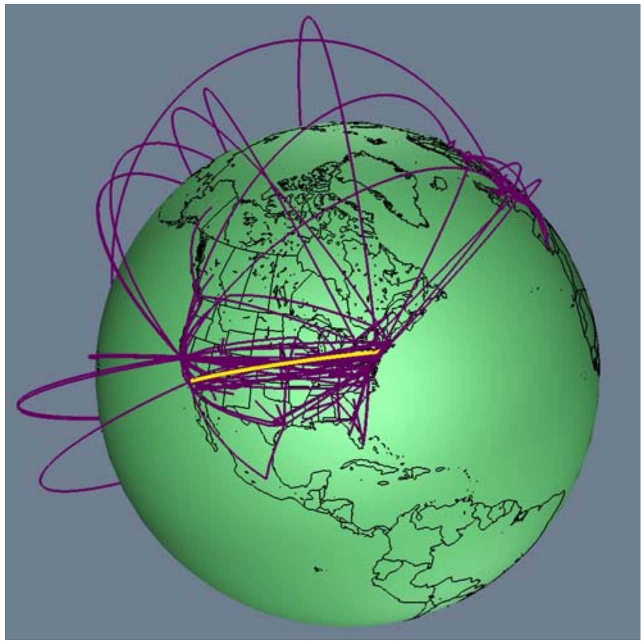


Figure 21: 3D arcs on a globe representation of the Internet MBone network.
(Courtesy of Tamara Munzner and IEEE, <http://www-graphics.stanford.edu/papers/mbone/>)

The final example is the Internet Mapping Project being undertaken by Hal Burch and Bill Cheswick at Lumeta Corporation (formerly at Bell Labs) (Branigan *et al*. 2001)[13]. Their project maps the topology of thousands of interconnected Internet networks to provide perhaps the best currently available large-scale overview of the core of the Internet in a single snapshot. They map the Internet in an abstract space (i.e. using a process of spatialisation), thus disregarding the actual location of nodes in physical space. Data is gathered by using the Internet to measure itself on a daily basis, surveying the routes to a large number of end-points (usually Web servers) from their base in New Jersey, USA. The resulting spatialisation maps how hundreds of networks connect together to form the core of the Internet. Figure 22 shows the structure of the Internet from December 2000, representing nearly 100,000 network nodes. This highly complex spatialisation takes several hours to generate on a typical PC. The layout algorithm uses simple rules, with forces

[13] <http://research.lumeta.com/ches/map/index.html>

of attraction and repulsion jostling the nodes into a stable, legible configuration. There are many permutations in the algorithm to generate different layouts and colour-codings of the links according to different criteria (such as network ownership, country). In the example shown, links have been colour-coded according to the ISP, seeking to highlight who 'owns' the largest sections of Internet topology. This project is ongoing and the data is archived and available to other researchers to utilise. Over time, it is hoped that the data will be useful for monitoring growth and changes in the structure of the Internet. The experience gained in mapping the Internet is also being applied commercially, using network scanning and visualization techniques to chart the structure of corporate intranets to identify security weaknesses and unauthorized nodes.

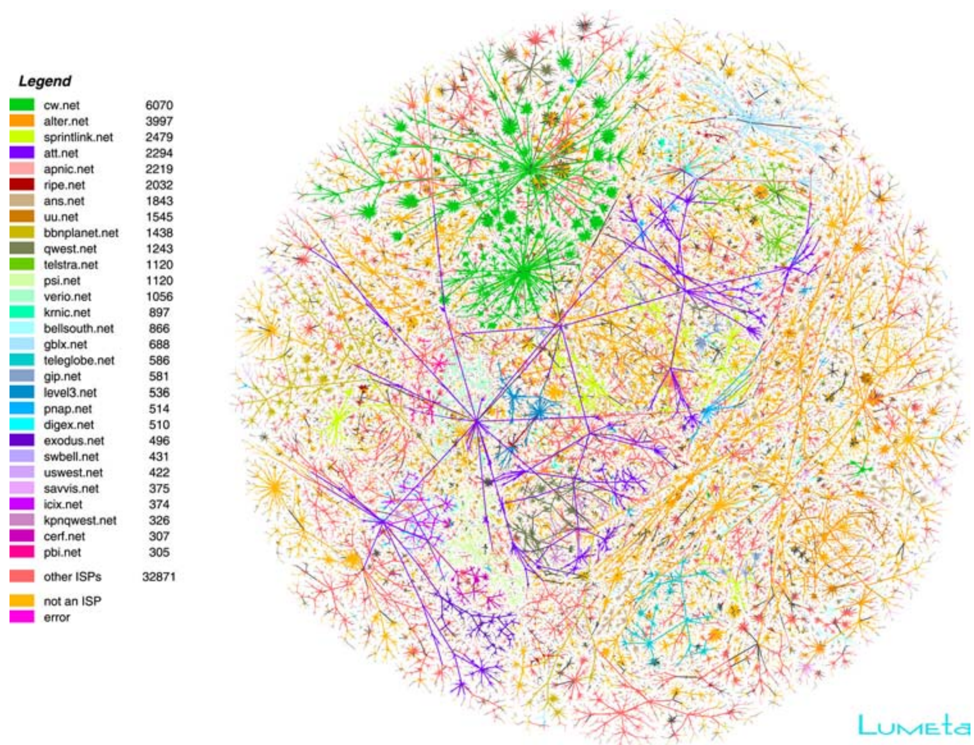


Figure 22: Map of the Internet topology by Hal Burch and Bill Cheswick.
(Courtesy of Lumeta Corporation, <http://www.lumeta.com>)

Conclusions

We have argued in this chapter that mapping can be used as a significant tool of analysis for managing Internet infrastructure, developing and implementing policy, and understanding the information economy. Maps can be used to reveal the range, extent and density of Internet infrastructure in relation to real-world geography at a variety of scales.

We finish on a note of caution, however. While mapping is a useful strategy, with many of the maps visually striking and persuasive, they need to be created, used and interpreted with care for four main reasons. First, maps are only as accurate as the data used in their construction. While, it is generally recognized that all spatial data are of limited accuracy due inherent error in data generation (e.g., surveying) or source materials, there are particularly acute problems in relation to data concerning the Internet. This is because what sources of data there are, are limited and fragmented, with few attempts to systematically measure the various components of Internet infrastructure. The problem is exasperated by the Internet's fast growing and dynamic nature that makes keeping up with changes almost impossible. Consequently maps are out-of-date before they are created as the component data they are constructed from has altered. In addition, the provision of both infrastructure and content services has become an intensely competitive and profitable business. As such, corporations are wary of giving away details that may aid competitors or threaten security, hence they police data relating to their own infrastructure (e.g. in relation to traffic flows). A further problem is there are no data standards for what data is produced. Hence different agencies produce different kinds of data, measured using varied techniques and so on. This makes comparison of data from different sources difficult. Consequently, most maps while fascinating are often limited in scope, coverage and currency because they are based on limited data.

Second, good maps require skilled construction. Maps necessarily depict a selective distortion of that which they seek to portray because they employ processes of generalisation and classification. Weak cartographic technique – and poor judgment on how best to generalise and classify - can lead to poorly constructed maps that have low communicability. At present, many of the maps of Internet infrastructure are not being created by trained cartographers. This means that many have poor cartographic design standards, using inappropriate styles or poorly chosen categorization. Consequently, many maps are lacking in legibility and some maybe misleading.

Third, due to a combination of the first two issues, many maps can propagate severe interpretation problems centered around issues of ecological fallacy. In regards to maps of infrastructure, ecological fallacy relates to the aggregation of data within spatial units – otherwise known as the Modifiable Areal Unit Problem (Openshaw 1984). The presentation of aggregated data can give the impression that all phenomenon within an area are similar, when in fact there could be significant variation. This can lead to inappropriate conclusions about that area. This is perhaps best revealed when the same data is mapped onto differing sets of spatial units (e.g., wards, districts, counties, states), as this can produce significantly different patterns across scales. Ecological fallacies are quite common (see Landweber example above), particularly when using secondary 'off-the-shelf' data such as that published by the World Bank, OECD, and International Telecommunications Union for example, because the data often relates to a particular scale (e.g. nations) but has no sub-scale variability. Consequently, there is little choice but to map it at the scale collected (see Dodge and Kitchin 2000b for a fuller discussion).

Lastly, all the maps we have discussed in this chapter have been created by people with a wide variety of motivations and agendas. As a consequence, all the maps are selective and subjective presentations of their underlying data, telling the 'story' their creators have designed them to tell – even if created in a so-called scientific fashion decisions have to be made over scale, symbols, layout, category classes, and what to map and what to omit. In many cases this 'story' will be benign, in others it will be carefully constructed. For example, maps used for marketing purposes are essentially pieces of corporate propaganda designed to highlight the range and scope of services on offer, communicating to a potential customer that they offer the 'right' network for them. As such, it is necessary to think about who the map was made for, by whom, why it was produced, and what are the implications of its message and use.

Given the diversity of map purpose, the variety of mapping techniques adopted, the problems with data capture and availability, and the subjective decisions made in their creation, it should be noted that there is no one single map or technique that can capture all the complexities of the Internet's infrastructure, and no such map can be created. Instead, there are a multiplicity of different Internet maps that focus on different components of the infrastructure. Perhaps, even, our knowledge is diminishing as the scale and complexity of infrastructure grows and information about it becomes less open to scrutiny. That said, we believe based on our review of the projects in this chapter that mapping can provide a highly useful tool in understanding and managing Internet infrastructure.

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